

The Elements of Physiology

WALTERS

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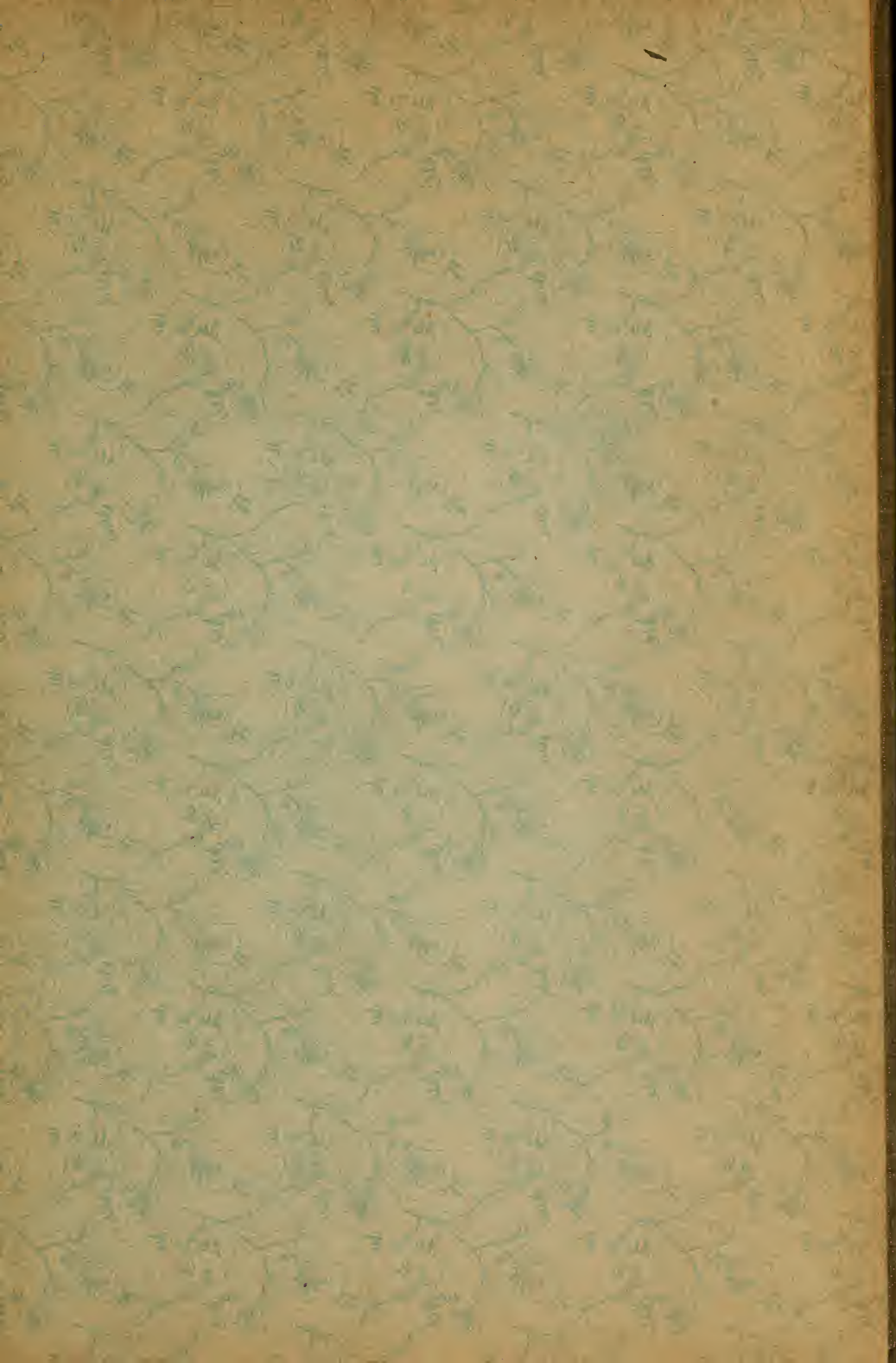


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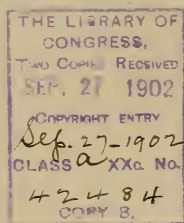
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THE ELEMENTS OF PHYSIOLOGY

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The *new physiology* differs from the old in the determination of the functions of organs from the inherent properties of their protoplasm, in the study of these functions in a great variety of animal types, especially of the lower forms, and in the frequent recourse to physical and chemical laws for explanations of phenomena.—*Loeb's Lectures on General Physiology.*



“It is quite possible to give instruction in this subject (physiology) in such a manner as not only to confer knowledge which is useful for itself, but to serve the purpose of a training in accurate observation, and in the methods of reasoning of physical science.”—*Huxley.*

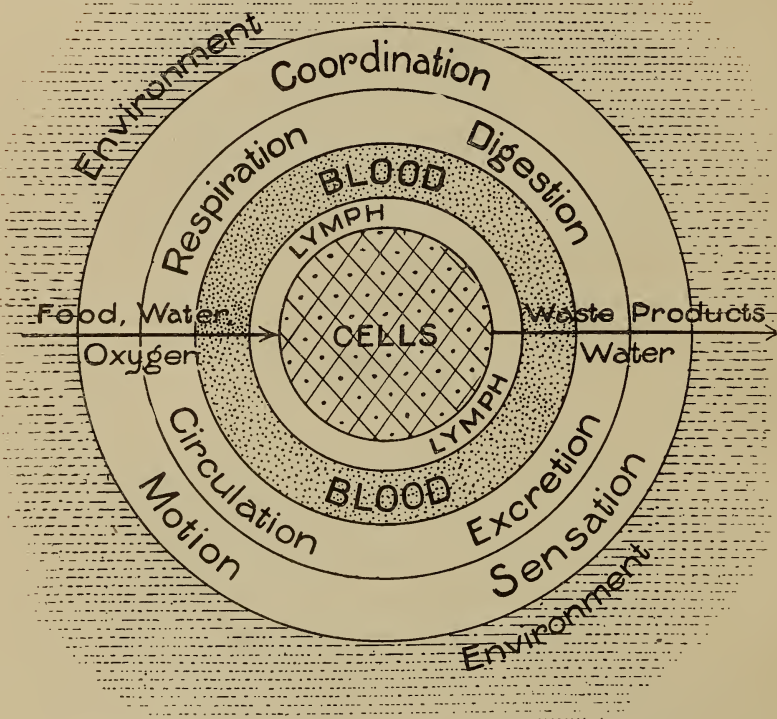


Fig. 1. The Physiological Scheme. See Summary of Part I, page 92, and Summary of Part II, page 176.

PREFACE.

This small treatise on the human body differs from the usual school text-books on this subject in the emphasis which is placed upon physiology. Only enough anatomy is introduced to construe the general structure of the body, while the hygiene is limited to suggestions and deductions growing out of a knowledge of physiology. The view is maintained that "the great art of right living" consists in the harmonious adjustment of one's habits to the nature and plan of the body. Such adjustment can be successfully accomplished only to the extent that one has a comprehension of the life processes and of the nature and extent to which they are influenced by modifiable conditions.

Another reason for placing the emphasis upon physiology is that by so doing the general purposes of education may be served as well as the practical purpose for which the body is studied. Physiology is a branch of natural science and, like biology, chemistry, or physics, may be so taught as to tax the reasoning powers, develop insight, and drill the pupil in the *modus operandi* of natural forces.

Much of the usual discussion of stimulants and narcotics has been curtailed for the reason that an undue amount of time spent in their consideration detracts from the symmetry of the subject and gives a distorted view of their *physiological* importance, and for the further reason that the general phases of these topics are properly considered in the lower grades. In confining this discussion to what seems to be its natural place in the pedagogical scheme, however, care has been taken to state accurately and pointedly the physiological objections to the use of alcohol, nicotine, and other poisonous drugs.

In the arrangement of the different chapters that order has been selected which promised to give the pupil, at each successive step, a deeper *insight* into the plan of the body. Since the body is but a

complex mechanism for the maintenance and transmission of life, the natural, or biological order, has seemed the one best adapted to this purpose. From the biological point of view the subject falls naturally into two divisions—the consideration, first, of the organs and the processes directly concerned in the maintenance of life and, second, of the mechanisms that co-ordinate the different parts of the body and bring it into proper relations with its environment.

Observational work should be carried on to the extent, at least, of obtaining clear ideas of the parts considered and of the processes involved in their operation. Systematic laboratory work, where it can be arranged for, is a most valuable aid in the mastery of the subject. Where this cannot be provided, class experiments and observations must be supplied by the teacher. The experiments and observations given in this book are for class purposes and are intended to serve a necessary part in the development of the subject. The list, which is suggestive rather than exhaustive, includes such as are simple and require little apparatus. A note book should be kept by the pupil.

The habitual use of books of reference in the study of physiology is earnestly recommended. For this purpose the usual high school books may be employed to good advantage. A few of the more advanced text-books should, however, be frequently consulted. For this use Martin's *Human Body, Advanced Course* (Henry Holt & Co., N. Y.), Rettger's *Advanced Lessons in Physiology* (Inland Publishing Co., Terre Haute, Ind.), Thornton's *Human Physiology* (Longmans, Green & Co., N. Y.), Huxley's *Lessons in Elementary Physiology* (The Macmillan Co., N. Y.), *An American Text-Book of Physiology* (W. B. Sanborn & Co., Philadelphia), Potter's *Quiz-Compend* (P. Blackiston's Son & Co., Philadelphia), Kimmins' *Chemistry of Life and Health* (Methuen & Co., London), Egbert's *Hygiene and Sanitation* (Lea Brothers & Co., Philadelphia), and Florence Nightingale's *Notes on Nursing* (D. Appleton & Co., N. Y.) will be found quite serviceable.

The subject matter of this book has been criticised by Dr. Thomas D. Wood, Physical Director, Teachers' College, Columbia Univer-

sity; by Dr. J. I. Anderson, practicing physician at Warrensburg, Mo.; and by Prof. J. L. Ferguson, Instructor in Physiology, State Normal School, Warrensburg, Mo. Rev. Dr. R. Neale of Warrensburg, and Mrs. Jennie E. Walters reviewed and criticised the literary features of the book, while the proof-sheets were kindly read by Profs. Deerwester, Seawell, and Ferguson of Warrensburg, and by Dr. C. C. Guthrie, Ass't Demonstrator, Medical Dep't, Western Reserve University. Dr. C. M. Jackson, Dep't Anatomy and Histology, Mo. State Univ., reviewed the portions on anatomy.

The drawings for the zinc etchings were prepared by S. Fred Prince, biological artist, Lincoln, Neb.

The general plan of the book, much of the subject matter, and most of the experiments and observations have been drawn from the author's *Physiological Class-Book*, publication of which is discontinued.

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THE ELEMENTS OF PHYSIOLOGY.

PART I.

THE VITAL PROCESSES.

CHAPTER I.

THE GENERAL CONSTRUCTION AND WORK OF THE BODY.

Definitions. The study of the human body falls naturally into three divisions, known as physiology, anatomy, and hygiene.

Physiology is the study of life processes and their interpretation, as far as is possible, in terms of known laws and facts. It may be *general* or *special*, according to whether it treats of life as manifested in a variety of animals or plants, or of the life processes in a single type. Human physiology is a special branch of the subject which deals with the function, or use, of the different parts of the body of man and of the relations they sustain to each other and to the body as a whole.

Of vital importance in the study of physiology is a knowledge of anatomy. *Anatomy* treats of the construction of living bodies—the nature and location of their parts and the materials from which they are formed. It is of two kinds, known as gross anatomy and histology. *Gross anatomy* is the study of the rough, coarse structures, while *histology* treats of the minute structures—those parts that are too small to be seen with the naked eye and which must be investigated with the aid of the microscope.

The practical value of physiology as a subject of study, in our public schools, lies in its bearing upon the health. Methods of caring for the body that relate directly to the health are considered under the subject of *hygiene*, while the conditions that must be observed for this purpose are termed the “laws of health.” Since these are all included

in the general principle that *right* habits of living *harmonize* with the plan of the body, the value of a knowledge of both physiology and anatomy from the standpoint of hygiene, is quite apparent.

Tissues. The body appears, from a hasty examination, to be a combination of several dissimilar substances, called tissues. For determining the relative extent and nature of the different tissues, the body of some small animal may be studied with profit.

Observation. Examine with care the different structures in the entire leg of a squirrel, rabbit, chicken or other small animal. Observe, first of all, the external covering, consisting of cuticle and hair, claws, scales or feathers, according to the specimen. These are similar in structure, and form the *epidermal* tissue. With a sharp knife lay open the skin and observe that it is attached to the parts underneath by thin, but tough, threads and sheaths. They represent a variety of structures which connect different portions with each other and are called *connective* tissue. The *muscular* tissue, which may now be examined and which forms the greater portion of the animal, is easily distinguished by its reddish appearance. With a blunt instrument, separate the muscles, by tearing apart the connective tissue sheaths, and find the tough strips of connective tissue (the *tendons*) which attach the muscles to the bones. Find near the central part of the leg some white glistening cords (*nerves*) which form one variety of *nervous* tissue. At the ends of the bones (*osseous* tissue) find a layer of smooth *cartilaginous* tissue. The *adipose*, or fatty, tissue is found immediately beneath the skin and between the other tissues.

Kinds of Tissues.* In an observation, such as the above, the following tissues should be found:

1. Epidermal tissue (three varieties). 2. Connective tissue (fibrous varieties). 3. Adipose or fatty tissue. 4. Muscular tissue (striated variety). 5. Osseous tissue. 6. Cartilaginous tissue. 7. Nervous tissue (*nerves*).

These tissues form the greater portion of the body. Others less abundant, but of considerable importance are: 8. The nervous tissue of the brain and spinal cord. 9. Non-striated muscular tissue. 10. Epithelial tissue.

Nature of the Tissues. The tissues serve a purpose in the body similar to that of wood, stone, plaster, iron and other like materials in a house. As the house is constructed from these building materials, so is the body built out of the tissues. For this reason the tissues have been called the *building materials* of the body. But the tissues

* In the more recent works on histology, the adipose, osseous, and cartilaginous tissues are classed as varieties of connective tissue, and the epidermal as a variety of epithelial tissue.

are also the means through which the work of the body is carried on, and in this sense, sustain a relation to the body additional and superior to that of building materials.

Properties and Uses of Tissues. Each tissue is found to serve some definite purpose in the body. It is also found to be perfectly adapted, by its properties, to its purpose. The properties of tissues like those of inanimate substances, are their distinguishing qualities, or characteristics, and may be either physical or chemical. With reference to hardness, toughness, color, weight, elasticity, and other properties, great variety is to be found among the different tissues. Furthermore, while each tissue may, and usually does, possess properties of minor importance, it also has properties which are indispensable in adapting it to its place in the body. Some of the more important of these essential properties are as follows:

1. Of osseous tissue, *hardness*, *toughness* and *stiffness*. 2. Of muscular tissue, *contractility*. 3. Of nervous tissue, *irritability*. 4. Of cartilaginous tissue, *stiffness* and *elasticity*. 5. Of connective tissue, *toughness* and *pliability*. 6. Of epidermal and epithelial tissues, *toughness* and resistance to the action of external agents.

Composition of Tissues. All tissues are made up of two distinct types of material. One of these consists of minute particles called *cells*; the other is a substance lying between the cells, known as *intercellular* material. The cells are, for the most part, too small to be seen with the naked eye, the largest not exceeding one two-hundredth of an inch in diameter. They are found to be unlike in the different tissues and to vary in form and properties to suit their places in the body.

The intercellular material is generally produced and deposited by the cells. Its quantity varies with age and increases with advance of years. It differs both in quantity and quality in the various tissues, and is the source of special physical properties such as the stiffness of bone and the elasticity of cartilage.

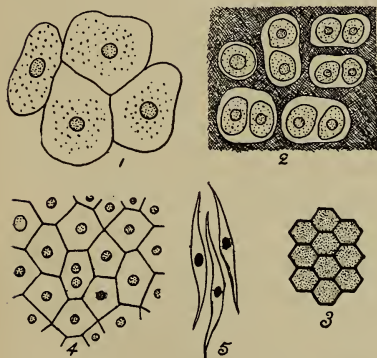


Fig. 2. Varieties of animal cells. 1. Epithelial cells from the mouth. 2. Cartilage cells. 3. Pigment cells from the retina. 4. Liver cells. 5. Non-striated muscle cells.

Observations. 1. Mix some of the scrapings, made from the inside of the cheek with a dull knife, with a little water on a glass slide. Place a cover glass on the same and examine with a compound microscope. The large cells that may be seen in this way are a variety of epithelial cells.

2. Mount in water on a glass slide some very thin slices of cartilage and examine first with a low and then with a high power. (Such slices may be cut with a sharp razor from the cartilage found at the end of a rib of a young animal.) Cartilage is remarkable for its intercellular material which forms a kind of bed for the cells.

3. Also mount and examine with the microscope, thin slices of elder pith, potato, and stems of growing plants. Make drawings of the cells thus observed.

Structure of the Cell. The cell is usually described as having three parts—the cell wall, the protoplasm, and the nucleus. The *cell wall* is a thin covering surrounding the other parts. It offers more or less protection to the cell contents, but since it is absent in



Fig. 3. A typical cell. 1. Cell wall. 2. Cytoplasm. 3. Nucleus. 4. Attraction sphere.

many instances it is not regarded as essential to the life of the cell. The *protoplasm* fills all the space within the cell wall and is the essential substance of the cell. It is semi-liquid and somewhat granular and resembles in appearance the white of a raw egg. Living protoplasm is capable of slight motion and responds to irritation. It can absorb and appropriate liquid food. It is absolutely essential to the cell and has been called the "physical basis of life." The *nucleus* appears as a clear rounded body within the protoplasm. It is concerned particularly with the formation of new cells and consists of a variety of protoplasm which is termed the *nucleoplasm*. Near the nucleus a small body has been discovered, named the *attraction sphere*, and within this is a denser portion called the *centrosome*. These also play some part in the development of new cells.

The entire cell is properly regarded as an organized bit of protoplasm, while the parts described above are but the modifications presented by it at different places. The cell contents, outside of the nucleus, is called the *cytoplasm*.

Conditions Surrounding the Cells. The cells of the body are *aquatic*, that is, they are surrounded by liquids which are essential to their life and activity. These liquids supply the cells with oxygen and food substances and receive and dispose of their waste materials. They find their way through the channels and spaces in the intercellular material of the tissues, keeping the cells well supplied with moisture. The liquid coming in immediate contact with the cells is called the *lymph*. A second liquid, the *blood*, replenishes the lymph and receives the waste that passes through the lymph from the cells.

Activities of the Cells. Each cell is the center of certain activities which are referred to as the work of the cell and which are in part general and in part special in nature. The *general work* of cells includes those activities that are necessary for their maintenance in the tissues and which are common to all cells. These are the absorption of liquid food and oxygen from the surrounding liquids, the production and addition of new material to the protoplasm, and the casting out of waste materials, or excretion. The *special work* of cells refers to the particular form of service that a given class of cells may render to the body as a whole. For example, the special work of muscle cells is to bring about the different movements of the body, while that of gland cells is to secrete various liquids.

Formation of new Cells. In all the tissues there occurs, at some stage in the growth of the body, the process of cell formation, or reproduction. In a few tissues, such as the epidermal, this process takes place continuously during life in order to supply new cells for replacing old and worn out ones. New cells are *always* formed from old ones. The most common plan by which this is accomplished is called *cell division*. By this plan a single cell after attaining its growth, separates into two or more new cells. The new cells thus formed begin at once to grow, absorbing liquid food and oxygen and may, upon attaining their full size, divide to form other new cells.

Importance of Cells. The body may be regarded as a vast collection of cells, of as many varieties as there are tissues, which are mutually helpful to, and also dependent upon, each other. All the work of the body is accomplished through its cells. The body grows through their growth and reproduction, and is nourished and kept alive through the agencies that nourish and keep alive the cells. A knowledge of the structure, growth, and work of its cells, therefore, is the first step toward a clear understanding of the body.

Organs and Systems. Any part of the body that has some special work to perform may be called an *organ*, as the eye, which is the organ of sight; or the hand, the organ for grasping. Any given organ will be found to contain the tissues necessary for its work. In an organ, like the hand, most of the tissues of the body are present, but in other organs, like the heart, fewer tissues are required.

A collection of organs working for the same end or purpose in the body is called a *system*. The heart, arteries, capillaries, and veins, for example, have for their common purpose the circulation of the

blood, and together form the circulatory system. In any system, the work of each organ must contribute to the work of the system as a whole.

The Plan of the Body. Even a slight knowledge of the body reveals such method and order in its manner of doing things that the existence of some comprehensive plan of structure and operation is at once suggested. Such a plan becomes the more apparent as the body is studied in detail, although its full comprehension is still one of the unsolved problems of science. An idea of the magnitude of the plan of the body may be obtained by simply enumerating the provisions that are necessary because of the peculiar needs of the cells. The cells in all parts of the body must be constantly supplied with liquid food and with oxygen and be relieved of waste materials. The whole cell group must be moved from place to place. All the parts must be warmed and kept at a uniform temperature. Different tissues must be kept in place and the form of the body preserved, while intelligent oversight, management, and protection of the whole group is demanded. In brief, the plan of the body must include all provisions that are necessary for

The Maintenance of Life. Herein lies the chief difficulty in fully understanding the plan of the body. The nature of life is unknown. As the biologist sees it, life is a peculiar condition associated with protoplasm. When this condition is present, the protoplasm is able to manifest its characteristic properties; but when it no longer exists, the protoplasm separates into the substances from which it is formed. The life condition may, therefore, be regarded as the organizer and preserver of the protoplasm. The maintenance of life is, of course, necessary to the existence of the body, and this is accomplished, as before stated, by providing favorable conditions for the cells.

Chemical Basis of the Body. When life ceases to exist in the protoplasm, and the materials forming the body separate, it is observed that one portion passes into the atmosphere, another mingles with the soil, and a third portion is water. This natural analysis of the body suggests that it is formed of materials that represent all three of the states of matter—solids, liquids, and gases. When they are subjected to further analysis by the chemist they are found to be made up of a number of the simple forms of matter, called elements. Among the more abundant elements in the body are carbon, hydrogen, oxygen, nitrogen, calcium, and phosphorus. Others, like sulphur, iron, magnesium, sodium, chlorine, and potassium are found in small quantities, while a number of unimportant ones are found in traces. None of the elements, however, exist in the body as such, but are com-

bined with each other to form a great variety of compounds, most of which are very complex. These compounds, called the *proximate principles*, form the chemical basis of the body and make up the substances both of the cells and the intercellular material.

Summary. Physiology is a study of life processes, the physical basis of which is protoplasm. This substance is organized into active units, called cells, of which there are found in the body several distinct varieties or types. Cells that are alike appear in groups, called tissues, which possess properties that adapt them to particular purposes in the body. The tissues are formed into working parts called organs and these are further combined into systems. Finally the body as a whole is an organization of protoplasm whose parts, although dissimilar in structure and function, combine in their several activities to perpetuate life.

Review Questions. 1. Distinguish between general physiology and human physiology; between gross anatomy and histology.

2. Of what value to hygienic living is a knowledge of physiology and anatomy?

3. Compare tissues with building materials. In what sense do they differ from building materials?

4. Show that the use made of the tissues is dependent upon their properties.

5. If a tissue be compared to a brick wall, to what do the separate bricks correspond? To what the mortar between the bricks?

6. Name and give use of each of the parts of a typical cell.

7. Compare the conditions surrounding a one-celled animal living in the water, to the conditions surrounding the cells in a tissue.

8. State the necessity for the different activities of the cells.

9. Give the different steps in the organization of protoplasm into the body.

10. What is an element? Name the four elements most abundant in the body. In what form do the elements exist in the body?

11. Enumerate the provisions in the plan of the body necessary to the maintenance of life.

CHAPTER II.

THE BLOOD.

Two liquids of similar nature are found in the body, known as the blood and the lymph. The former is kept moving rapidly through a system of tubes called the blood vessels, while the latter lies in minute spaces in the intercellular material and flows slowly through a second system of tubes called the lymphatics. Both liquids minister to the wants of the cells. The study of lymph will be deferred to a later period.

The Properties of Blood are shown by the experiments which follow. Secure through the assistance of a butcher (see Appendix) a bottle of blood which has been allowed to coagulate without shaking or stirring; a bottle of defibrinated blood; and a bottle of blood which has been kept from coagulating by mixing with Epsom salts.

Experiments. 1. Let some of the defibrinated blood flow (not fall) on the surface of water in a glass vessel. Does it remain on the surface or sink to the bottom of the vessel? What does the experiment show with reference to the relative weight of blood and water?

2. Place a small amount of the dark defibrinated blood in a large test tube, or bottle, and thin it by adding an equal amount of water. Then place the hand over the mouth of the tube and shake until the blood is thoroughly mixed with the air in the vessel. Compare with a portion of the blood not mixed with air and notice any difference in color. What substance in the air in the test tube probably acted on the blood to change its color?

3. Fill three tumblers each two-thirds full of water and set in a warm place. At intervals of one-half hour pour into each, and thoroughly mix with the water, two tablespoonfuls of blood containing the Epsom salts. The water dilutes the salts so that coagulation is no longer prevented. Jar the vessel occasionally as the coagulation proceeds. After the blood has been added to the last tumbler make a comparative study of all. Note that the coagulation begins in all parts of the liquid at the same time and that, as the process goes on, the clot shrinks and is drawn toward the center.

4. Place a clot from one of the tumblers in experiment three, in a large vessel of water. Thoroughly wash, adding fresh water until a clear, white, stringy solid remains. This substance is called *fibrin* and is the cause of the coagulation.

5. Examine the coagulated blood in the bottle obtained from the butcher. Observe the dark central mass (the clot) surrounded by a clear liquid (the serum). Sketch the vessel and its contents, showing and naming the two parts into which the blood separates by coagulation.

The foregoing and other experiments show the blood to be heavier and denser than water; to have a faint odor and a slightly sweetish taste; to have a bright red color when it contains oxygen and a dark red color when oxygen is absent; and, when exposed to certain conditions, to undergo a change called coagulation. These properties are to be accounted for through the peculiar

Composition of the Blood. To the naked eye the blood appears as a thick but simple liquid. When, however, it is examined with a compound microscope, it is seen to be made up of two distinct parts—a clear transparent liquid and many small, rounded bodies which float in the liquid. The liquid portion is called *plasma*, the small rounded bodies are known as *corpuscles*. Two varieties of the latter are described as *red* and *white* corpuscles. A third variety may also be observed under favorable conditions, called *blood platelets*, in addition to some very minute particles or granules.

Observation. Examine with a compound microscope a small drop of human blood. (See Appendix.) If the blood be too thick to distinguish individual corpuscles, it may be diluted with a little water or a small amount of a very dilute solution of salt in water. The red corpuscles will appear as amber-colored, circular, disk-shaped bodies which show a decided tendency to arrange themselves in rows, resembling rows of coins. (They do not appear red because there is not sufficient coloring matter in single corpuscles.)

A few white corpuscles may generally be found among the red ones. They are easily recognized by their larger size and their silvery appearance which is due to the light shining through them. Sketches should be made showing the relative size and general arrangement of the corpuscles on the slide.

Structure and Function of the Red Corpuscles. The red corpuscle may be regarded as a single cell, although it has no nucleus and is supposed to be without a cell wall. It consists of a little mass of elastic and somewhat spongy protoplasm, called the *stroma*, which is saturated with a reddish coloring matter, called *haemoglobin*. It has the shape of a thin, circular disk with concave sides. In size it is about one thirty-two hundredth of an inch through the long diameter and about one-fourth as thick. The red corpuscles are exceedingly numerous, it being estimated that in health there are as many as five millions in a small drop of blood. The number, however, is greatly diminished during various forms of disease.



Fig. 4. A cluster of red corpuscles, in the center of which is a white corpuscle.

The *function* of the red corpuscles is to serve as *oxygen carriers* in the body. They absorb oxygen at the lungs which they give up to the cells in the different tissues. They owe this property entirely to the presence of the

Haemoglobin. This substance has the remarkable property of forming, under certain conditions, a weak chemical union with the oxygen and, when the conditions are reversed, of separating from it. The differences in the conditions to which the blood is subjected, at the lungs and in the tissues, will be considered later. The haemoglobin forms about nine-tenths of the solid matter of the red corpuscles and gives them their color. The stroma, which forms the remainder, serves as a contrivance for holding the haemoglobin.*

Origin of Red Corpuscles. As the red corpuscles are constantly being destroyed in various ways, new ones have to be regularly supplied to take their place. Their origin is not entirely accounted for, though the best authorities agree that a large per cent of them is formed in the red marrow of the bones.

The White Corpuscles are irregular in shape and are larger than the red ones, their average diameter being about one twenty-five hundredth of an inch. They are much less numerous, however, there being in healthy blood only about one white corpuscle to every three hundred and fifty red corpuscles. They are for this reason, not easily observed in the blood. They may be obtained in abundance from lymphatic glands.

Observation. Obtain from a butcher a small piece of the neck sweetbread of a calf. Press it between the fingers to squeeze out a whitish, semi-liquid substance. Dilute this with water on a glass slide and examine with a compound microscope. Numerous white corpuscles, of different kinds, will be found. Make sketches.

The white corpuscles are endowed to some extent with the power of motion and are able to change their shape. For these reasons they are migratory in the body, being able to penetrate the walls of small blood vessels and to pass between the cells. They collect in large numbers at the parts of the body that may be inflamed and form a consid-

* A solution of haemoglobin may be prepared by cutting and bruising a blood clot in a vessel of water and then straining the liquid through a coarse piece of muslin. Such a solution differs from a simple mixture of blood and water in its ability to transmit light. Because of its transparency print is easily read through it, while the presence of corpuscles would render the liquid opaque.

erable portion of the white matter found in sores, called pus. They originate in the lymphatic nodules.

Functions of the White Corpuscles. The white corpuscles serve a variety of purposes, the following being the most important:

1. They consume living organisms, known as bacteria, that find their way into the blood and cause various diseases.

2. They form a kind of wall, or covering around any foreign substance, such as a splinter, that may penetrate the skin, and prevent in this way the spread of poisonous matter through the system. They serve a similar purpose in the case of boils and ulcers, isolating as it were the infected part from the rest of the body.

3. They supply an active agent or ferment which, by acting on the coagulable material of the blood, causes coagulation. This ferment is given up at the time of the escape of blood from wounds and because of the injury which the white corpuscles sustain.

The Plasma is a very complex liquid, consisting of water with a large number of substances dissolved in it. The latter may be grouped into the following classes:

1. Albumins, of which three varieties are recognized, known as *serum albumin*, *globulin*, and *fibrinogen*. They resemble the white of raw egg, and differ in the readiness with which they coagulate.* They all serve as food for the cells, while the fibrinogen, in addition to this, is the chief agent in the coagulation of the blood.

2. Carbohydrates and fats. These exist in small quantities in the blood and are food for the cells.

3. Salts. Common salt, or sodium chloride, is the most abundant member of this class, although several others are present. The salts serve various purposes, one of which is to cause the albumins to dissolve in the plasma.

4. Waste products. These are received by the blood from the different cells and are carried by the plasma until removed by the organs of excretion.

Cause of Coagulation. Fibrinogen is the coagulable constituent of the blood. When exposed to the action of a peculiar chemical agent, called *fibrin ferment*, it readily changes into a white, stringy mass known as *fibrin*. Fibrin ferment does not exist in the blood in its

* Fibrinogen coagulates more readily than the others and is the only one that separates by the ordinary coagulation of the blood. The others remain dissolved during this process, but are coagulated by chemical agents and heat.

normal condition. It is formed, however, when the blood is exposed to some influence which causes a disintegration of the white corpuscles and blood platelets. Another element which is necessary to the process of coagulation is a small amount of calcium. If this is absent, coagulation does not occur. By the combined action then of the fibrin ferment and the calcium, the fibrinogen changes into fibrin. This, forming at first as fine threads throughout the whole mass of blood and entangling the corpuscles, later contracts and draws the corpuscles into the solid mass call the *clot*. *Serum*, the liquid squeezed out of the clot by the contracting fibrin, contains all the constituents of the plasma except the fibrinogen.

The Purpose of Coagulation is to check the flow of blood from small wounds. Clots forming in the mouths of blood vessels when they are cut or broken, close them up, and stop the flow of blood which would otherwise go on indefinitely.

The rate of coagulation is increased by heat and retarded by cold. It may be prevented entirely by lowering the temperature to near the freezing point. The presence of a foreign substance also affects the rapidity of coagulation, and it has been observed that bleeding from small wounds is quickly checked by covering them with cotton or linen fiber.

Changes in the Blood. In performing its work in the body the blood must of necessity undergo rapid and continuous change. The red corpuscles, whose changes have already been noted, are the most stable constituents of the blood. The plasma is the part that is changed most rapidly. There is, however, such an adequate control of the supply of materials to the blood, and of the removal of materials from the blood, that its general composition and density do not vary from time to time. An excess of certain impurities prompts a greater activity of the organs of excretion. If the blood becomes too dense, a feeling of thirst prompts one to drink water. Likewise, a scarcity of food material causes hunger and a lack of oxygen in the blood induces a desire for a deep breath of air. In time of fasting the blood obtains food materials from the tissues. Even the quantity of blood remains nearly constant during the changing conditions of food and water supply, and variations in the health and activity of the body.

The total quantity of blood is estimated at one-thirteenth of the entire weight of the body. This for the average individual is an amount weighing nearly twelve pounds and having a volume of nearly one and one-half gallons. About forty-six

per cent by volume of this amount consists of corpuscles and fifty-four per cent of plasma. Of the plasma ten per cent consists of solid materials and ninety per cent of water.

Hygiene of the Blood. An adequate supply of good blood is both a safeguard to the health and a most important agent in the recovery from disease. Moreover, the condition of the blood is largely dependent upon one's habits of living. From a health standpoint, the most important constituents of the blood are the red corpuscles. These are generally sufficient in number and vigor in the blood of those who take plenty of physical exercise, expose the body freely to outdoor air and sunlight, and indulge in plenty of sleep. On the other hand they are deficient in quantity and inferior in quality in those who pursue an opposite course. Impurities frequently find their way into the blood through the digestive organs. One should eat wholesome, well cooked food, drink freely of pure water, and limit the quantity of food to what can be properly digested. The natural purifiers of the blood are the organs of excretion. The skin is one of these and its power to throw off impurities depends upon its cleanliness and the activity of the circulation through it. Alcoholic beverages, if taken in considerable quantity, have a very injurious effect upon the blood, and interfere with its work in the body.

Patent medicines for purifying the blood, as a rule, do more harm than good. One may safely rely upon wholesome food, pure water, outdoor exercise, sunlight, plenty of sleep, and a clean skin, for keeping the blood in good condition. When these natural agencies fail, a physician should be consulted.

Summary. The blood is a necessary means of supplying conditions favorable for the cells. It may be regarded as a convenient liquid from which they derive their nourishment and into which they expel their waste. Its properties and composition are such as to adapt it to these purposes and its changes are the unavoidable results of its work in the body.

Review Questions. 1. Compare blood and water with reference to density, weight, and complexity of composition.

2. Compare the red and white corpuscles with reference to size, shape, number, origin, and function.

3. Explain the cause and purpose of coagulation.

4. After coagulation, what portions of the blood are found in the clot? What portions in the serum?

5. What per cent of the blood (omitting that in the corpuscles) is water? What purposes are served by the water in the blood?

6. Show how the blood, though constantly changing, is kept about the same in quantity, density, and composition.

7. At the lungs the blood changes from a dark to a bright red color and in the tissues back to a dark red. What is the cause of these changes?

8. What property of haemoglobin enables the red corpuscles to serve as an oxygen carrier?

9. What habits must be practiced and what avoided in keeping the blood in good condition?

CHAPTER III.

CIRCULATION OF THE BLOOD.

The blood is a *moving* liquid. Its regular movement through the body—starting at one place, flowing out to the different parts and returning to that place—is termed its circulation.

The Discovery of the Circulation of the Blood was made in 1616 by an English physician named Harvey. In 1619 he taught it in his public lectures and in 1628 published the result of his investigations. No other single discovery with reference to the human body has proved of so great importance. A knowledge of the nature and purpose of the circulation was the necessary first step in understanding the plan of the body and the method of maintaining life. Hence, physiology as a science dates from the time of Harvey's discovery.

The Necessity for the Circulation lies in the fact that the blood acts as a *carrier* for the cells. Oxygen from the lungs, and liquid food from the digestive organs, reach the cells through the blood. Likewise, the blood must convey the impurities from the cells to the organs of excretion. To accomplish these results *the blood must move*. So great is the necessity for the circulation that its stoppage, for only a brief interval of time, results in death.

The Organs of Circulation, or blood vessels, are of four kinds—named the heart, arteries, capillaries, and veins. They serve as contrivances both for holding the blood and for keeping it in motion through the body. The heart, which is the chief organ for propelling the blood, acts as a force pump, while the arteries, capillaries, and veins serve as tubes for conveying the blood from place to place. All are so connected that the blood passes through them in a regular and definite order.

Observation on the Heart. Procure, by the assistance of a butcher, the heart of a sheep, calf or hog. To insure the specimen against mutilation, the lungs and diaphragm must be left attached to the heart. In studying the different parts, good results will be obtained by observing the following order:

1. Observe the connection of the heart to the lungs, diaphragm, and large blood vessels. Inflate the lungs and observe the position of the heart with reference to them.

2. Examine the sac surrounding the heart. It is called the *pericardium*. Pierce its lower portion and collect the pericardial fluid. Increase the opening thus made until it is large enough to slip the heart out through it. Slide back the pericardium until its attachment to the large blood vessels above the heart is found. Observe that a thin layer of it continues down from this attachment, making the outer covering of the heart.

3. Trace out for a short distance and study the veins and arteries connected with the heart. The arteries are to be distinguished by their thick walls. Carefully remove and save for later study a section each of an artery and vein, three or four inches in length. The heart may now be severed from the lungs by cutting the large blood vessels, care being taken to leave a considerable length of each one attached to the heart.

4. Observe the outer portion of the heart. The thick lower portion contains the cavities called *ventricles*; the thin upper ear-shaped portions are the *auricles*. The thicker and denser side lies toward the left of the animal's body and is called the *left* side of the heart; the other is the *right* side. Locate the right auricle and the right ventricle; the left auricle and the left ventricle.

5. Lay the heart on the table with the front side up and the apex pointing from the operator. This places the left side of the heart to his left and the right side to his right. Notice the groove between the ventricles, called the *interventricular groove*. Make an incision half an inch to the right of this groove and cut towards the base of the heart until the pulmonary artery is laid open. Then, following within about half an inch of the groove, cut down and around the right side of the heart. The wall of the right ventricle may now be raised and the cavity exposed. Observe the extent of the cavity, its shape, its lining, its columns of muscles (*columnae carneae*), its half columns of muscles (*musculi papillares*), the tendinous cords (*chordae tendinae*), the tricuspid valve from the under side, etc. Also notice the valve at the beginning of the pulmonary artery, and the sinuses or depressions in the artery immediately behind its divisions.

6. Now cut through the middle of the loosened ventricular wall from the apex into the right auricle, laying it open for observation. Notice the openings (one each for the superior vena cava, the inferior vena cava, and the coronary vein). Compare walls, lining, shape, size, etc., with the ventricle below.

7. Cut a cross section from the left ventricle about an inch from the apex. This will show the extension of the left ventricle to the apex; it will also show thickness of its walls and the shape of the cavity. Split up the ventricular wall far enough to examine the mitral valve and chordae tendinae from the lower side.

8. Make an incision in the left auricle. Examine its inner surface and find the places of entrance of the pulmonary veins. Examine the mitral valve from above. Compare the two sides of the heart part for part.

9. Separate the aorta from the other blood vessels and cut it entirely free from the heart, care being taken to leave enough of the heart attached to the artery to insure the semi-lunar valve being left in good condition. After closing up the openings in the sides of the aorta, pour water into the small end and observe the closing of the semi-lunar valve. Repeat the experiment until the action of the valve is understood. Sketch the artery showing the valve in a closed condition.

The Human Heart does not differ materially in structure from the heart which has been studied. It is about the size of the clinched

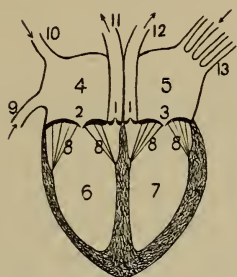


Fig. 5. Diagram of the heart. 1. Semi-lunar valves. 2. Tricuspid valve. 3. Mitral valve. 4. Right auricle. 5. Left auricle. 6. Right ventricle. 7. Left ventricle. 8. Chordae tendinae. 9. Inferior vena cava. 10. Superior vena cava. 11. Pulmonary artery. 12. Aorta. 13. Pulmonary veins.

fist of the owner, and is situated very near the center of the thoracic cavity. It is pear-shaped and so placed that the small end extends downward and to the left. Read in some larger work a description of the heart, noting the structure and location of valves and the differences in the structure of the walls surrounding the cavities. The general plan of the heart and its connections with the larger arteries and veins are indicated in Fig. 5.

The *pericardium* forms a protective covering for the heart. It consists of a closed sac

so arranged as to form a double layer around the heart. The inner layer blends closely with the tissues of the heart, forming its exterior lining. The outer layer loosely surrounds the other and connects at places with the membranes of the lungs. The free surfaces secrete a small quantity of liquid which occupies the pericardial sac and prevents friction in the heart's movements.

How the Heart Does Its Work. The heart is a hollow muscle and does its work by contracting and relaxing. When it contracts, its cavities are closed and the blood is forced from them. When it relaxes the cavities open and the blood flows in to refill them. Valves prevent the backward flow of blood. The heart's action may be readily illustrated in the following manner:

Procure a syringe bulb with an opening in each end. Attach a rubber tube to each end of the bulb, letting the tubes reach into two tumblers containing water. By alternately compressing and releasing the bulb water is pumped from one vessel into the other. The bulb may be taken to represent one of the ventricles. What action of the ventricle is represented by compressing the bulb? By releasing the pressure?

By making the proper connections with a greater length of tubing, and filling the whole with water, the entire circulation may be represented. Show by a sectional drawing the arrangement of the valves in the syringe bulb.

The Arteries and Veins form two systems of tubes which extend, by their divisions, from the heart to all parts of the body. The arteries receive the blood from the heart and distribute it to the capillaries. The veins receive the blood from the capillaries and return it to the heart.

Observation. Examine carefully the artery and vein saved from the dissection of the heart. Compare them with reference to the thickness, elasticity, and toughness of their walls. Which is able to stand open? After allowing them to lie in water over night separate each into its layers or coats.

Both arteries and veins have three coats. The *inner* coat consists of thin, flat cells, united at their edges and is continuous with the lining membrane of the heart. The *middle* coat consists mainly of non-striated muscular tissue. In the artery it is very thick. The *outer* coat is largely connective tissue.

The arteries and veins differ in several important respects and are easily distinguished. The walls of the arteries are thicker and heavier than those of the veins. They are also highly elastic, while the veins are but slightly elastic. On the other hand, many veins contain valves and the entire venous system holds more blood than the system of arteries.

Experiment. Close up the small end of the aorta, which was cut from the heart during its dissection and which has in it the semi-lunar valve, with a close-fitting cork having two openings. In one opening a pointed glass tube should be fitted and in the other a straight glass tube for attaching it by a rubber tube with a syringe bulb, or force-pump. Force water into the artery and observe:



Fig. 6. Illustrating the elasticity of arteries. See experiment.

1. That the artery swells and may be filled overfull. 2. That the water is forced out through the small tube when there is no pressure from the pump. (The small arteries branching from the aorta, should be tied or plugged before forcing in the water.)

The Advantage of the Elasticity of the Arteries is two-fold: 1. It prevents the bursting of the arteries when the blood is emptied into them from the ventricles. 2. It is a means of keeping the blood in the arteries under *continuous* pressure, although the ventricles exert their pressure only at intervals. During the contraction of the ventricles the arteries are filled over-full and have to swell out to

make room for the excess of blood. Then while the ventricles are relaxing, the arteries exert their elastic force to keep the blood flowing steadily into the capillaries. In thus causing an otherwise intermittent flow to become a continuous and steady stream, the elasticity of the artery serves a purpose similar to that of the air-chamber of a force-pump.

The Valves in the Veins enable pressure at different parts of the body to force the blood toward the heart. The muscles, for example, in contracting, press against the sides of the veins and tend to empty them at those places. Since the valves are closed by any backward movement, the force of the muscle can drive the blood in but one direction and that is toward the heart. Scarcely a movement of the body can be made without compressing the veins at some point and, as a rule, the valves are found in greatest abundance where the compressions are most likely to occur. The valves in the veins are, therefore, an economical device to enable pressure, that would otherwise interfere with the circulation, to assist in the process.

Observations. Exercise the arm a few minutes to increase its blood supply. Expose the forearm and examine the veins on its surface. With the finger stroke one of the veins toward the shoulder. Much of the blood can be forced out of it. Now stroke the vein toward the hand. The blood is not forced backward but the vein swells instead, the swelling being greatest at one or two places resembling "knots." These knots mark the position of valves which prevent the return of blood to the hand.

The Muscular Coat serves two important purposes. In the first place it, together with the elastic tissue, keeps the capacity* of the blood vessels equal to the volume of the blood that is circulating. In the second place it serves as the active agent in regulating the amount of blood that goes to a given organ. It accomplishes the latter purpose by varying the capacity of the artery going to the organ. To increase the blood supply the muscle relaxes and the artery is dilated by the blood pressure within. To diminish the supply the muscle contracts making the capacity of the artery less. The muscular coat receives nerves from the central nervous system by which it is controlled.

* The total capacity of the blood vessels is considerably greater than the volume of blood which they contain. It is only by keeping their walls contracted or in a condition of "tone" that the pressure from the heart can be transmitted to all parts of the blood stream and the circulation be maintained.

Important Arteries and Veins. The two main arteries are the *pulmonary artery* and the *aorta*. The first receives blood from the right auricle and, through its divisions, passes it to all parts of the lungs. The second receives the blood from the left ventricle and, by its branches, distributes it through the entire body.

The most important veins are the *pulmonary* (usually four, but sometimes three, in number) which pass the blood from the capillaries of the lungs to the left auricle, the *superior vena cava* which connects with the right auricle from above, and the *inferior vena cava* which joins the right auricle from below. The superior vena cava is formed by the union of veins from the arms, head, and upper part of the trunk, while the inferior vena cava is formed by the union of veins from the lower extremities, and the middle and lower part of the trunk. The *portal* vein, because of its size and function, is also of considerable importance. It receives blood from the stomach, intestines, and other abdominal organs and conveys it to the liver.

The Capillaries consist of a network of minute blood vessels which connect the terminations of the smallest arteries with the beginnings of the smallest veins. They have an average diameter of less than one two-thousandths of an inch, and their walls consist of a thin layer of cells placed edge to edge. This structure renders them porous, and enables the plasma of the blood and the white corpuscles to penetrate their walls. With a few exceptions, they are found in great abundance in all parts of the body.

Observation. Study with a compound microscope the circulation of the blood through the capillaries in the web of a frog's foot. For an extended examination it is best to destroy the frog's brain. (See Appendix.) The frog may be attached to a thin board which has an opening in one end over which the web of the foot may be stretched. Threads should extend from two of the toes to pins driven in the board to secure the necessary tension of the web and the foot and lower leg should be kept moist. By careful work single capillaries may be traced back to the small arteries from which they branch, and forward to the veins which they help to form. The appearance is truly wonderful, but allowance must be made for the fact that the *motion* of the blood is magnified and that it moves much more slowly than it appears to.

Functions of the Capillaries. Because of the thinness of the capillary walls and their porous structure, liquids readily penetrate them. This enables the capillaries to serve the two-fold purpose of admitting substances into the blood and of passing substances from the

blood. In the absorption of liquids at the digestive organs and of oxygen at the lungs they serve the former purpose and in the distribution of substances at the various tissues, the latter. It is only at the capillaries that the blood is able to receive and give up its constituents. In addition to this function the capillaries, by the degree to which they penetrate the various tissues, bring the blood very near the individual cells.

Divisions of the Circulation. Man, in common with all warm-blooded animals, has a double circulation, a fact which explains the double structure of the heart. The two divisions are known as the *pulmonary* and *systemic* circulations.

By the former the blood passes from the right ventricle through the lungs and is then returned to the left auricle; by the latter it passes from the left ventricle through all parts of the body, returning to the right auricle. All of the blood flows continuously through both circulations and passes the various places in the following order: Right auricle, tricuspid valve, right ventricle, right semi-lunar valve, pulmonary artery and its branches, capillaries of lungs, pulmonary veins, left auricle, mitral valve, left ventricle, left semi-lunar valve, aorta and branches, systemic capillaries, veins, superior and inferior venae cavae and then again into the right auricle. At the lungs the blood gives up carbon dioxide and receives oxygen.

In the systemic capillaries it gives up its oxygen and receives carbon dioxide and other impurities.

In addition to the two main divisions of the circulation, special modifications of the general plan are found in various places. Such a modification in the liver is called the *portal* circulation and another in the kidneys is termed the *renal* circulation. To some extent the blood



Fig. 7. Diagram of the circulation. 1. Systemic divisions. 2. Pulmonary division. 3. Through the kidneys. 4. Portal circulation. 5. Visceral circulation. 6. Connection with the lymph vessels. 8. Aorta.

supply of the walls of the heart is outside of the general plan, and has been designated the *coronary* circulation.

Hygiene of the Circulatory Organs. The heart being a muscle, is subject to the laws of muscular exercise. It may be injured by over-exertion but is strengthened by a moderate increase in its usual work. It may even be subjected to great exertion without danger by gradually increasing the amount of work that devolves upon it. Such a course, by giving the heart time to gain in size and strength, prepares it for tasks that could not at first be attempted. Injury is frequently done the heart of the amateur athlete, bicyclist, or mountain climber, through attempting more than the previous training warrants. Active exercise during short periods, followed by intervals of rest, such as the exercise furnished by the climbing of stairs, or by short runs, is considered the best means of strengthening the heart.

Since the heart is controlled by the nervous system, it frequently becomes irregular in its action through nervous disorders. It is through their effect upon the nervous system that worry, over-study, undue excitement, or dissipation, cause disturbances of the heart. In all such cases the remedy lies in the removal of the cause. A number of drugs, among which is alcohol, interfere, through their effect upon the nerves, with the normal action of the heart. The nicotine of tobacco produces an undesirable effect in two ways: 1. Where the use of tobacco is begun in early life, it interferes with the normal development of the heart muscle, leading to marked weakness in the adult. 2. When used in considerable quantity by young or old, it induces a distressing nervous condition, known as the "tobacco heart." Coffee used to excess, also interferes with the nervous control of the heart.

The presence of valves in the veins shows that part of the force to move the blood should come from the bodily movements. While the heart is able to propel the blood when the body is in a condition of repose, the benefit of different movements, as utilized by the valves, cannot be doubted. Daily physical exercise may, therefore, be looked upon as a necessary condition for the efficient and healthful circulation of the blood.

Suggested Topics for Further Study. 1. Quantity of work performed by the heart.

2. Sounds of the heart.

3. Effect of bodily exercise on the activity of the heart.—Count the number

of pulsations per minute (a) when in a sitting posture, (b) when standing, (c) after walking, and (d) after running.

4. Circulatory systems of other animals.—Compare the systems of the insect, fish, reptile, and warm-blooded animal.

5. Methods of checking the flow of blood from wounds.

6. Variations in blood pressure and velocity in the arteries, veins, and capillaries.

Summary. The blood, to serve as a carrier of materials to and from the cells, must be kept moving throughout the entire body. The blood vessels contain the blood, supply the channels and the force necessary for its circulation, and provide conditions for the entrance of materials into, and their exit from the blood. The heart is the chief factor in propelling the blood, although the muscles and elastic tissue in the arterial walls and the valves in the veins are necessary aids in the process. At the capillaries the blood takes on and gives off materials. The arteries and veins serve chiefly as tubes for transferring the blood from place to place. All the organs of circulation are under the control of the nervous system.

Review Questions. 1. Of what special value to the study of the body, was the discovery of the circulation of the blood?

2. State the necessity for a circulating liquid in the body.

3. Show by a drawing the general plan of the heart, locating and naming the essential parts.

4. Explain the heart's method of propelling a liquid.

5. Of what use are the valves in the heart? In the veins?

6. Why should there be a difference in structure between the two sides of the heart?

7. Of what advantage is the elasticity of the arteries?

8. State the purpose of the muscular coat.

9. How is the blood forced from the capillaries back to the heart?

10. If the rest period following each contraction of the heart is one-third as long as the period of contraction, how many hours is the heart able to rest out of every twenty-four?

11. State the functions of the capillaries.

12. Trace the blood through a complete circulation, beginning with the left auricle.

13. What physical exercises tend to strengthen the heart? What ones tend to injure it?

14. State the effects of tobacco upon the heart.

CHAPTER IV.

LYMPH AND THE LYMPHATICS.

Necessity for the Lymph. The blood, it will be remembered, moves everywhere through the body in a system of *closed* tubes. It can therefore come in contact only with those cells which line the blood vessels. The capillaries, to be sure, bring the blood very near the cells of the different tissues; still there is need of a liquid to fill the space between them and the cells and to transfer materials from one to the other. The lymph occupies this position and does this work. The position of the lymph with reference to the capillaries and cells is shown in Fig. 10.

Origin of the Lymph. The chief source of the lymph is the plasma of the blood. As before described, the walls of the capillaries consist of a single layer of thin cells placed edge to edge. Partly on account of the pressure upon the blood and partly on account of the natural tendency of liquids to pass through animal membranes, a considerable portion of the plasma penetrates the thin walls and enters the spaces occupied by the lymph.

Another source of lymph is material from the cells. This is of the nature of waste, but it adds to the bulk of the lymph. A considerable portion of the material absorbed from the alimentary canal, as well as liquids absorbed through the skin, also enter the lymph before passing into the blood. The lymph, however, consists chiefly of the blood plasma that has passed through capillary walls.

The Composition of the Lymph, as would be expected, is quite similar to that of the blood. In fact, nearly all the important constituents of the blood are found in the lymph, but in different proportions. Food materials for the cells exist in smaller proportions than in the blood, while the impurities from the cells exist in larger proportions. As a rule the red corpuscles are absent from the lymph, but the white corpuscles are found there in greater abundance than in the blood.

Physical Properties. The lymph is a colorless and slightly alkaline liquid, heavier and denser than water, though not so dense as

blood. It has the power of coagulating, but coagulates more slowly than blood.

Kinds of Lymph Vessels. Most of the lymph of the body lies in the minute cavities surrounding the cells. These are called *lymph spaces* and correspond, in a way, to the capillaries. Connected with these are a great number of slender tubes, with thin walls, called *lymphatics*. These resemble veins in purpose and, like the veins, have valves. They differ from veins, however, in being more uniform in size, and in having very thin walls.



Fig. 8. Connection of the main lymphatic ducts with the circulation. 1. Superior vena cava. 2. Thoracic duct. 3. Right lymphatic duct. 4. Right subclavian vein. 5. Left subclavian vein.

These gradually converge toward, and empty into, the two main lymph tubes of the body. The smaller of these, called the *right lymphatic duct*, represents the convergence of the lymph vessels of the right arm, the right side of the head, and the region of the right shoulder and it empties into the right subclavian vein. The larger, known as the *thoracic duct*, connects with the lymph tubes in the remaining parts of the body and empties into the left subclavian vein. Fig. 8.

The lymph tubes that join the thoracic duct from the small intestine are called *lacteals*. While these do not differ in structure from the tubes in the other parts of the body, they perform a special work in the absorption of fat.

Movements of the Lymph. Though the lymph may be regarded as a comparatively quiet liquid, it has three well defined movements, as follows: 1. That of a current passing from the capillaries toward the cells. 2. A current which moves from the cells toward the capillaries. 3. A movement of the entire body of lymph along the lymph channels, toward the larger lymph vessels. Fig. 10.

Return of the Lymph to the Blood. The lymph vessels are generally regarded as a division of the circulatory system, and the lymph may be looked upon as a portion of the blood which will,

sooner or later, return to the blood vessels. A large part of the lymph re-enters the blood at the capillaries, by the process of osmosis, while the remainder finds its way back through the lymph channels. The latter passes first from the lymph spaces into the lymphatics. It then moves through these tubes until it enters either the thoracic duct or the right lymphatic duct. From these it flows into the subclavian veins. Fig. 8.

Causes of the Flow of Lymph. There is no force pump, like the heart, connected with the lymphatics, and the flow of the lymph is brought about by forces which act indirectly. The more important of these are the following: 1. *Blood pressure in the capillaries.* The plasma which is forced through the capillaries by pressure from the heart makes room for itself by pushing

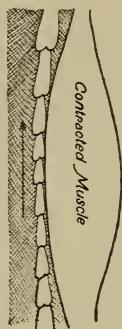


Fig. 9. Illustrating the action of the muscles in propelling the lymph.

a portion of the lymph out of the lymph spaces. This in turn presses upon the lymph in the tubes which it enters. In this way pressure from the heart may be transmitted to the lymph. 2. *By variable pressure on the walls of the lymph tubes.* The pressure exerted on the sides of the lymph tubes, by contracting muscles, will close them at certain points, and push the lymph past valves which prevent its return. Pressure at the surface of the body, provided that it is variable, also forces the lymph toward the heart. The valves serve the same purpose in the lymph vessels as in the veins. 3. *The inspiratory force.* When the thoracic cavity is enlarged, in breathing, unbalanced atmospheric pressure forces

the lymph toward the cavity, and into the veins, in the same manner that it forces air into the lungs.

The Lymphatic Glands, or lymphatic nodules, are small, rounded bodies situated along the course of the lymph tubes. They vary in size, some of the largest being an inch or more in length. The lymphatic vessels generally open into them on one side and leave them on the other. They are not glands in function, but are so called because of their having the general form of glands. They provide favorable conditions for the development of white corpuscles. (P. 10.)

Interchange of Materials at the Cells. Food substances and oxygen in passing from the blood through the lymph into the cells must penetrate both the wall of the capillary and that of the cell. These are likewise penetrated by the impurities which flow from the cells back to the blood. The passage of these substances occurs, in

part at least, in accordance with the principle known as *osmosis*, or *dialysis*.

Osmosis Illustrated. If a vessel with an upright, membranous partition be filled on the one side with pure water and on the other with water containing salt, an interchange of material will take place through the membrane until the same proportion of salt exists on the two sides. Osmosis is also illustrated by the following

Experiment: Separate the shell from the lining membrane at one end of an egg, over an area an inch in diameter. To do this without injuring the membrane, the shell must first be broken into small pieces and then picked off with a pair of forceps, or a small knife blade. Fit a small glass tube, eight inches long, into the other end so that it shall penetrate the membrane and pass down into the yolk. Securely fasten the tube to the shell by melting bees-wax around it, and set the egg in a small tumbler partly filled with water. Examine in the course of half an hour. What evidence now exists that water has passed through the membrane into the egg?

The Conditions under which Osmosis Occurs are as follows: 1. The liquids on the two sides of the membrane must be *unlike* either in composition or in density. In case of a difference in density the greater flow of liquid is toward the denser substance. 2. The liquids must be capable of wetting or penetrating the membrane. If but one liquid penetrates the membrane the flow will take place in one direction only. 3. The liquids must be of such a nature as to mix readily.

Osmosis at the Cells. Oxygen and food materials which are found in great abundance in the blood, are less abundant in the lymph and still less abundant in the cells. According to the principle of osmosis* the flow of oxygen and food materials will be from the capillaries toward the cells. On the other hand the impurities are most abundant in the cells where they are formed, less abundant in the lymph, and least abundant in the blood. Hence the impurities will flow from the cells toward the capillaries. Fig 10.

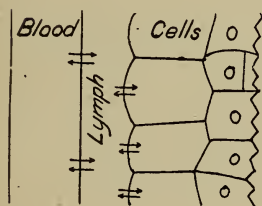


Fig. 10. Relation of the lymph to the blood and the cells.

The Work of Water both in the exchanges at the cells and in

*The interchange of materials through membranous walls is not fully accounted for by osmosis alone and it is quite probable that other forces are concerned in the process.

the circulation of the blood and the lymph may here be noted. The solid substances in these liquids are either dissolved in or floated by the water and by it are carried along.

In this way water serves as a transporting and distributing agent without which the exchanges at the cells and between different parts of the body would be impossible.

Summary. The exchange of materials, between the cells and the blood, takes place through the lymph. Its composition and location adapt it to this purpose. It consists chiefly of escaped blood plasma, while the vessels that contain it are a part of the general circulatory system. The lymph is continually finding its way, through suitable channels, back into the blood stream.

Review Questions. 1. State the necessity for the lymph in the body.

2. Compare lymph and water with reference to density, color, and composition.

3. Compare blood and lymph with reference to composition, physical properties, and movement through the body.

4. Compare the lymph tubes and the blood vessels with reference to general structure and the different kinds.

5. Show how blood pressure at the capillaries causes a flow of the lymph.

6. Trace the lymph in its flow from the right hand to where it enters the blood. From the feet to where it enters the blood.

7. What conditions prevail at the cells to keep the oxygen continually flowing in one direction and impurities in the opposite direction?

8. What part does water play in the exchanges at the cells?

CHAPTER V.

RESPIRATION.

Through the circulation of the blood and the lymph, the cells in all the tissues are placed in communication with the surface of the body. Any substance which enters the blood at the surface will be carried to the cells. On the other hand, any substance which enters the blood at the cells may be carried to the surface and there removed from the body. It is now our purpose to consider some of the materials that are made to pass from the outside of the body to the cells and vice versa. Two of these substances are constituents of the atmosphere.

The Atmosphere, or air, completely surrounds the earth, as a kind of envelope, and comes in contact with everything upon its surface. It is composed chiefly of two colorless gases known as oxygen and nitrogen, but it also contains minute portions of other substances such as carbon dioxide and watery vapor. Because of its weight it exerts continuous pressure which, at sea level, amounts to nearly fifteen pounds to the square inch. The atmosphere forms an essential part of one's physical environment and serves the body in various ways.

Respiration, or breathing, is carried on by alternately taking air into and expelling it from special contrivances in the body, called the lungs. The act of taking air into the lungs is known as *inspiration*; that of expelling it, *expiration*.

The Purpose of Respiration, as indicated by the changes which air undergoes in the lungs, may be shown by the following

Experiments: 1. Fill a quart jar even full of water. Place a heavy piece of cardboard over its mouth and invert it, without spilling, in a pan of water. Inserting a tube under the jar, blow air, that has been held as long as possible in the lungs, into the jar. When filled with air, remove the jar from the pan, but keep the top well covered. Slipping the cover slightly to one side, insert a burning splinter and observe that the flame is extinguished. This proves the absence of sufficient oxygen to support combustion. Pour in a little lime-water

(see Appendix) and shake to mix with the air. The change of the lime-water to a milky white color indicates the presence of carbon dioxide.

2. Blow the breath against a cold window pane. Note and account for the collection of moisture.

Air taken into the lungs in ordinary breathing, parts with about five per cent of itself in the form of oxygen and receives about four per cent of carbon dioxide, and a small quantity of watery vapor. These changes suggest a two-fold purpose of respiration:

1. To obtain from the atmosphere the supply of oxygen needed in the body. 2. To transfer to the atmosphere certain materials (waste products) which must be removed from the body.

The Respiratory Organs, taken together, form an apparatus for dealing with matter in the gaseous state and are constructed with reference to the properties of the atmosphere. They include the following parts:

1. A special arrangement of moist vascular membrane which enables the air to come very near a large surface of the blood.

2. *A system of air passages*, or tubes, which connect this vascular surface with the outside atmosphere.

3. *The thorax* which provides a cavity for holding the principal organs of respiration and to which is attached

4. *A muscular mechanism* which forces the air through the air passages.

5. *A nervous mechanism* which regulates the respiratory movements.

These parts are more or less combined in, and their action centered around, what is recognized as the special organ of respiration, called

The Lungs. The lungs consist of two sac-like bodies which are suspended in the thoracic cavity and which occupy most of the space not taken up by the heart.

Observation. Secure from a butcher the lungs of a sheep, calf, or hog. The windpipe and heart should be left attached and the specimen kept in a moist condition until used. Study in the following order:

1. Examine the large open tube (consisting of the larynx and the trachea) and the closed tube lying back of it (the oesophagus). Observe the cartilaginous plates in the larynx and the rings in the trachea. What purpose do they serve? Remove and make a drawing of a ring of the trachea.

2. Insert a tube in the trachea and inflate the lungs, noting the number of times their volume is thus increased.

3. Examine the thin membrane (the pleura) inclosing the lungs. Strip off a piece and test its elasticity.

4. Sever the small upper lobe from the remainder by cutting the bronchial tube. Split this tube a short distance into the lung, observing its smooth lining and the openings of the smaller tubes or branches from it. Are the rings in these like those of the trachea? Make cross sections of this portion of the lung and find the openings of the lesser bronchial tubes.

5. Follow the trachea down to where it branches to form the bronchi. Find a branch of the pulmonary artery which approaches one of the bronchi and trace both the bronchus and artery into the lung. Observe that as one branches the other branches, until the smallest divisions are reached. The pulmonary veins also lie alongside the bronchial tubes, but are not so easily traced as the arteries.

6. Place a piece of lung upon water. In floating what portion is submerged? Inference.

The lungs represent the combined mass of many air sacs, together with the air tubes and blood vessels associated with them. (Read the general description of the lungs and air passages in some larger work.)

The Air Passages provide a continuous passageway between all parts of the lungs and the outside atmosphere, through which air is passed in both directions. The separate parts which form the passages, named in the order that air goes through them, in entering

the lungs, are the nostrils, pharynx, larynx, trachea, bronchial tubes, and the lesser bronchial tubes. Only the upper part of the pharynx can be properly classed as an air passage. The lower portion is a part of the food canal, while the middle provides a suitable cross-roads for the air tract and the passageway of the food. Fig. 11. Air may also enter the pharynx through the mouth. This is necessary in many instances, but in ordinary breathing is objectionable. The larynx, in addition to being an air passage, serves as the organ of the voice.



Fig. 11. Relation of the pharynx to other passages. 1. Pharynx. 2. Larynx. 3. Oesophagus. 4. Trachea. 5. Nostril. 6. Mouth. 7. Eustachian tube. 8. Lachrymal duct.

Additional Work of the Air Passages. The air is prepared in going through the different passages for entrance into the more delicate portions of the lungs. Especially must it be changed in temperature and in the amount of moisture that it contains and also, in many instances, freed from dust particles. A large amount of

this preparatory work is done in the nostrils where the air is made to pass over a large surface of warm and moist mucous membrane. For this reason breathing should be through the nostrils.

To enable the air to move easily through the different passages it is necessary that they be kept open and clean. They are kept *open* by special contrivances found in their walls. In the trachea, bronchi, and larger bronchial tubes these consist of imperfect rings of cartilage. In the small tubes most of the cartilage disappears, its place being taken by connective tissue. The walls of the larynx contain strips and plates of cartilage, while the nostrils and pharynx are kept open by their bony surroundings.

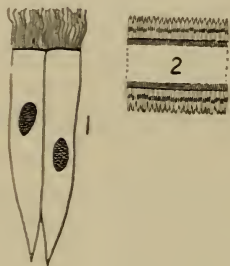


Fig. 12. Ciliated epithelial cells. 1. Cells detached. 2. In position in a small air tube.

is their small hair-like projections called cilia. These cells line the mucous membrane in most of the air passages and are so placed that the cilia extend into the open space in the tubes. Fig. 12. The cilia keep up an inward and outward wave-like motion which has greater force in the *outward* direction. The effect of this is to carry any foreign matter, such as dust particles and bits of partly dried mucus or phlegm, to where it may be easily expelled from the lungs.

Terminal Air Spaces. Each of the smallest divisions of the bronchial tubes terminates in a sac-like enlargement, called the *infundibulum*. This by a process of infolding divides its inclosed space into a number of small rounded cavities which are known as the air-cells, or alveoli. These vary somewhat in shape and size, the average ones being about one one-hundredth of an inch in diameter. Fig. 13.



Fig. 13. Terminal air space.

Each alveolus is surrounded by a delicate wall of elastic connective tissue which supports a dense network of capillaries and is lined by a single layer of flat cells placed edge to edge. This arrangement brings

air very near a large surface of blood and makes possible the exchange of gases. At no place in the lungs, however, does the air come in direct contact with the blood but their exchanges always take place through both the capillary walls and the walls of the alveoli.

Observation. Inflate the lungs of some small animal, as a cat or rabbit, and examine the divisions as they may be seen at the surface. The smaller divisions are the alveoli; the larger ones the infundibula.

The Blood Supply of the Lungs. The pulmonary artery and its branches convey the blood from the right ventricle to all parts of the lungs. The branches lie alongside of and divide similarly to the bronchial tubes, and finally join the capillaries that surround the alveoli with which the lesser bronchial tubes connect. From the capillaries the blood is returned to the heart by the pulmonary veins. These lie alongside of the arteries and bronchial tubes and unite to form the veins which empty their contents into the left auricle. This arrangement brings practically all the blood through the capillaries that surround the terminal air spaces. Fig. 14.

The lungs also receive blood, through small branches from the aorta, which supplies nourishment to the different parts.

The Thorax, or chest, is that part of the trunk between the neck and the abdomen which incloses a space known as the thoracic cavity. The framework of the thorax is furnished by the ribs, the portion of the spinal column with which the ribs connect, and the sternum or breastbone. The ribs form gliding joints with the spinal column and connect with the sternum in front by strips of cartilage. They do not encircle the thoracic cavity in a horizontal direction but

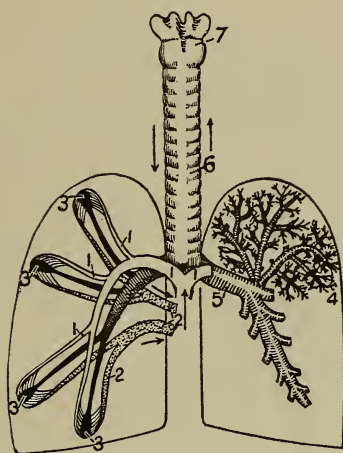


Fig. 14. Diagram of the lungs. 1. Branches of the pulmonary artery. 2. Pulmonary veins. 3. Terminal air space. 4. Bronchial tubes. 5. Bronchi. 6. Trachea. 7. Larynx. The arrows indicate the movements of the air and the blood.

slant downward and outward from the back. Attached to the ribs are many small muscles which, by their contraction, elevate the ribs and expand the chest. The thoracic cavity is separated from the cavity below by a movable partition, called

The Diaphragm. The margins of the diaphragm are firmly attached to the walls of the thorax at the place where they blend with the walls of the abdomen. Its outer margin is muscular, while the central portion consists of a heavy sheet of connective tissue. The diaphragm is in an arched condition, being kept in this form by pressure from the organs below and by its connection above with the membrane of the thoracic cavity, known as

The Pleura. This is a thin and elastic, but tough membrane which covers the outside of the lungs and lines the inside of the chest walls. The layer covering each lung is continuous with that of the chest wall on the same side and forms with it a closed sac by which the lung is surrounded. Properly speaking then, there are two pleurae and these, besides inclosing the two lungs, partition off a middle space which is occupied by the heart. Each pleura also covers the upper surface of the diaphragm on the same side and then deflects upward from the center to join the pericardium. A small amount of liquid is secreted by the pleural lining which prevents friction as the surfaces glide over each other in breathing.

How Air is Brought into and Expelled from the Lungs. The principle involved in breathing is that air flows from a place of *greater* to a place of *less* pressure. The construction of the thorax adapts it to the application of this principle. Its walls are air-tight and it is able, by changing the size of the cavity within it, to produce alternately a place of *less* and a place of slightly *greater* pressure than that of the atmosphere on the outside of the body.

The lungs are suspended from the upper portion of the thoracic cavity and are always sufficiently filled with air to keep their outer surface pressed against the chest walls. The trachea and the upper air passages provide the only opening to the outside atmosphere. When the thorax is enlarged, making an area of less pressure within, the greater pressure of the atmosphere on the outside, forces the air into the lungs, causing them to expand and fill the extra space within the cavity. When the thorax is diminished in size the air within the lungs is slightly compressed, causing it to exert greater pressure by its

elastic force than the atmosphere exerts on the outside. This causes air to flow out until the equality of pressure is again restored.

In this connection a hand bellows, such as is used in kindling fires, may be studied with profit, its action being similar to that of the thorax. Observe that when the sides are spread apart air flows into the bellows. When they are pressed together the air flows out. If a sac be hung in the bellows with its mouth attached to the projecting tube and the valve in the side of the bellows closed it would represent almost exactly the plan of the breathing organs. Fig. 15.



Fig. 15. The respiratory and the hand bellows. Compare part for part.

Experiment. With a tape line take the circumference of the chest of a boy, when he has expelled from the lungs all the air possible. Take it again when he has them inflated to their utmost capacity. The difference in the measurements represents the change of chest capacity. What does this experiment show with reference to the cause of breathing?

How the Thorax Changes its Capacity. Breathing, as shown above, is accomplished through changes in the thoracic space. This is *increased* by the elevation of the ribs and the depression of the diaphragm. The former process increases the transverse diameters; the latter the longitudinal diameter. The ribs are raised by the action of the muscles attached to them. The diaphragm, being naturally in an arched position, is depressed by the contraction of the muscles within it. As it lowers it pushes down the contents of the abdomen.

Experiment. With five narrow strips of cardboard, one eight inches long and each of the others six inches, construct a figure to represent the thorax. Let the long strip serve as the spinal column and one of the short ones as the breast bone. Fasten the others between them for ribs. The fastenings, which must admit of motion, may be made by pushing pins through the strips where they join.

Holding the piece representing the spinal column in a vertical position, raise and lower the piece representing the breast bone. When is the space between the upright pieces the greatest? Apply to the action of the ribs in increasing the thoracic cavity.

The capacity of the thorax is *diminished* by lowering the ribs and elevating the diaphragm. Ordinarily the ribs are lowered, when the muscles that elevate them relax, by their own weight and by the elastic

reaction of the surrounding parts. In forced expiration, however, special muscles are brought into play. The diaphragm is not raised through its own action, but is *pushed* up by the contents of the abdomen. These, in turn, are pressed upward by the contraction of muscles in the abdominal walls.

To Estimate the Quantity of Air Breathed. Experiment. (a) Fill a half gallon fruit jar even full of water, cover the top with a stiff piece of paper, and invert, without spilling, in a pan of water. Insert a tube under the jar and blow the air expelled from the lungs in *ordinary* breathing into the jar. Count the number of expirations required to fill the jar and then calculate the quantity breathed out during a single expiration. This equals the amount breathed in at an average inspiration, and is called the *tidal* air.

(b) Fill and invert the jar as before. This time, after an *ordinary* inspiration, empty the lungs as completely as possible. (A second vessel should be ready to receive the excess of air in case the jar should prove too small.) This air, less the tidal air, is called the *reserve* air.

The air that is left in the lungs after the forced expiration is called the *residual* air. In quantity it nearly equals the sum of the tidal and the reserve air. From the results obtained calculate the capacity of the lungs tested. (For the average individual the ordinary capacity of the lungs is equal to about one gallon. In forced inspiration the quantity is increased about one-third, by what is called the *complemental* air.)

Hygiene of Respiratory Organs. The liability of the lungs to attack from such a dread disease as consumption, makes questions touching their hygiene of first importance. Consumption never attacks sound lung tissue, but always has its beginning at some weak or enfeebled part of the lungs, which has lost its "power of resistance." Neither is consumption inherited as many suppose. Weak lung tissue, however, may be transmitted from parents to children and this accounts for the frequent appearance of consumption in the same family. Consumption, as well as the other respiratory affections, can in the majority of cases be *prevented* by an intelligent observation of well known laws of health.

Respiratory Health Rules.

1. Breathe through the nostrils.
2. Maintain an erect position both in sitting and standing.
3. Practice deep breathing sufficiently to insure the easy access of air to all parts of the lungs.
4. Wear clothing loose enough around the chest and waist to allow perfect freedom in the respiratory movements.

5. Never permit a cold to settle on the lungs. If it cannot be relieved by counter-irritation, a physician should be consulted.

6. Take active exercise in the open air. Exercise which causes a notable increase in the respiratory acts is of especial value in strengthening the lungs.

7. Avoid smoking and the use of alcoholic drinks. Tobacco smoke irritates the upper air passages, causing in some instances what is called "the smoker's sore throat."

Ventilation. The health of the respiratory organs and of the entire body as well, demands the breathing of *pure* air. By pure air is meant that which contains the same proportion of oxygen as the general atmosphere. (How does breathing render air impure?) Ventilation is the process of bringing pure air into a room, and of getting rid of the air which is unfit for breathing purposes. Since warm air is lighter than cold air, suitable openings in the walls of dwellings enable currents of air to pass between the rooms and the outside atmosphere. Care must be taken, however, to prevent drafts and to avoid too great a loss of heat from the rooms. The plan of ventilating must be adapted to the construction of the building, plan of heating, and the general condition of the weather. No specific directions can be given.

The general rules below may be followed with good results in ventilating rooms where the air is not heated before being brought in.

1. Introduce air into the room through many small openings instead of a few large ones.

2. Introduce the air at the warmest portions of the room.

3. Provide openings both at the upper and lower parts of the room.

4. If a wind is blowing ventilate principally from the sheltered side of the house.

Suggested Topics for Further Study. 1. The nature and action of the respiratory muscles.

2. Relation of the pressure of the atmosphere to the process of breathing.

3. Relation of respiration to the activity of the body. Determine the number of respirations per minute (a) during rest and (b) after vigorous exercise.

4. General lung structure. Remove and study the lungs of a frog. Observe their general structure when inflated. (The terminal spaces, at the ends of the bronchial tubes, are similar in structure to the entire lung of the frog.) The specimen may be dried, while inflated, and preserved for future study.

5. The action of cilia. Make a study of cilia as follows: (a) Expose the

back part of the mouth and the gullet of a recently killed frog. Drop on the surface some small shavings of cork and watch for any movement. The cilia will move the particles backward toward the stomach. (b) Mount some small particles, cut or scraped from such a specimen, on a glass slide, in a very weak solution of salt in water, and examine under a microscope, first with a low and then a high power. In the slowly moving cilia it may be observed that the motion is quicker in one direction than in the other.

6. Artificial respiration. Study in some larger work the methods of applying artificial respiration.

Summary. The lungs form a contrivance for bringing about an exchange of gases between the air and the blood. Their construction and operation are in harmony with the nature and the properties of the atmosphere which supplies the oxygen that enters the blood and receives the gases that leave the blood. The exchange of gases takes place at the air-cells, or alveoli, where the air comes very near a large surface of blood. The air is brought into and expelled from the lungs through the action of the respiratory muscles which alternately increase and diminish the cavity of the thorax.

Review Questions. 1. How does the air leaving the lungs differ in composition from that entering them?

2. Name the air passages in their order.
3. Describe the air spaces at the terminations of the bronchial tubes.
4. How are the air passages kept open and clean?
5. Give three reasons for breathing through the nostrils.
6. How is air brought into and expelled from the lungs?
7. Give functions of the diaphragm.
8. If thirty cubic inches of air pass into the lungs at each inspiration and .05 of this is retained as oxygen, calculate the number of cubic feet of oxygen consumed each day, the number of inspirations being eighteen per minute.
9. Find the weight of a day's supply of oxygen, as found in the above problem, allowing 1.3 ounces as the weight of a cubic foot.
10. Make a study of the school room with reference to its hygienic ventilation.
11. Give general directions for the care of the lungs.

CHAPTER VI.

THE PASSAGE OF OXYGEN THROUGH THE BODY.

What is the nature of oxygen? What is its purpose in the body and how does it serve this purpose? How is it taken up and given off by the blood? What becomes of it after being used? These are questions touching the maintenance of life and deserve careful consideration.

The Properties of Oxygen are readily learned by examining it in an undiluted form. For method of generating and collecting it see Appendix. Four large-mouthed bottles filled with the gas are needed in the following

Experiments: 1. Examine a bottle of oxygen noting its lack of color. Insert a small burning splinter in the upper part of the bottle and observe the change in the burning. Remove quickly and extinguish the flame, leaving only a spark on the end of the splinter. Lower the spark into the oxygen and observe the result. Repeat until the oxygen in the bottle is exhausted.

2. Hollow out the end of a short piece of crayon, fasten a wire holder to it, and fill the cavity with powdered sulphur. Ignite the sulphur in the flame of an alcohol lamp and lower it into a bottle of oxygen. Observe the change in the rate of burning, the color of the flame, and the material formed in the bottle by the burning. The gas remaining is sulphur dioxide and has been formed by the *uniting* of the sulphur and the oxygen.

3. Bend a small loop on the end of a piece of picture wire. Heat the loop in a flame and insert in some powdered sulphur. Ignite the melted sulphur which adheres and insert it quickly in a bottle of oxygen. Observe the dark brittle material which is formed by the burning of the iron. It is a compound of oxygen and iron, similar to iron rust, and has been formed by their *uniting*.

Oxygen is an element of intense affinity, or combining power, and, because of this fact, is able to unite with many other elements to form *compounds*. It may unite slowly, as in the rusting of iron, or rapidly as shown in the preceding experiments. Combustion, or burning, is but a *chemical uniting* of oxygen and certain substances, attended by light and heat. Oxygen is therefore described as the

supporter of combustion. It supports combustion, however, by the simple method of uniting with the substances which burn and which are called *combustibles*. The substances which are formed by the burning, called *products of combustion*, are compounds of oxygen and the combustibles. It is thus seen that oxygen in common with other elements appears in two forms: First, that in which it is in a free, or uncombined, condition—the form in which it appears in the atmosphere. Second, that in which it is a part of compounds, as in the products of combustion.

The general term for designating the uniting of oxygen with other substances is *oxidation*. This includes combustion as well as the unions which take place more slowly.

The Passage of Oxygen Through the Blood is effected by means of its relations with the haemoglobin of the red corpuscles. The oxygen and the haemoglobin are able to unite if brought in contact where the oxygen pressure,* or tension, is greater than about half a pound to the square inch, but they will not unite, and they separate, if already united, where the oxygen pressure is less than half a pound. At the lungs the oxygen pressure is nearly three pounds to the square inch, but this diminishes in the arteries, becomes still less in the capillaries, and falls to zero in the cells. This enables the blood to flow constantly from a place of high to a place of low oxygen pressure, and, in so doing, to take up the oxygen at the lungs and release it at the tissues.

The Purpose of Oxygen. In the cells the oxygen is constantly uniting with the hydrogen and carbon which form a large part of the protoplasm and the food substances. This action, similar in many respects to the combustion in a stove, is in effect a *continuous* chemical change, in nature an oxidation, that never ceases during life. Evidence of this action of oxygen is found in its continuous disap-

* Dalton has shown that the ability of gases to dissolve in liquids varies with the pressure to which they are subjected. It is also true that pressure increases the tendency of a gas to unite chemically with a liquid or solid. Where two or more gases are mixed, as in the atmosphere, each exerts the same pressure that it would if it were alone and the pressure of the mixture is the sum of the partial pressures of the several gases. Since oxygen comprises about one-fifth of the atmosphere, the pressure which it exerts is one-fifth of the total pressure or, at the sea level, about three pounds per square inch. ($15 \times \frac{1}{5}$.) This is the oxygen pressure of the atmosphere. The lack of oxygen pressure in the tissues of the body is due to its scarcity and this to its rapid consumption at the cells.

pearance as a free element in the body and in the appearance of products of oxidation.

The maintenance of a condition of continuous oxidation is the chief and, it may be, the only purpose of oxygen in the body.* As a result of the oxidations, energy is liberated (Chapter XI) and substances are formed which are added to the protoplasm, either to take the place of other material or to enable it to grow. At the same time materials are produced which cannot be used in the body and which must be disposed of as waste.

Oxygen and the Maintenance of Life. In the setting free of energy in the body and in the formation of materials which may be added to the protoplasm, conditions necessary to the maintenance of life are provided. Because of the close relation of oxygen to these processes, as well as the observed fact that the stoppage of the supply results in death, it is frequently called *the supporter of life*. The substances with which it unites are, however, just as necessary to the maintenance of life as is oxygen. The dependence of life upon them appears less marked than in the case of oxygen, because they are accumulated, or stored up, in the body, while oxygen must be continually supplied from the atmosphere as it is needed.

Passage of Oxygen from the Body. In the oxidation of materials at the cells, oxygen leaves its free state and becomes a part of the compounds which are the products of oxidation. With carbon it unites to form carbon dioxide (CO_2); with hydrogen it forms water (H_2O); and with nitrogen, hydrogen, and carbon it forms urea ($\text{N}_2\text{H}_4\text{CO}$). These substances pass through the blood to the organs of excretion where they are removed as waste. It is through their removal that the oxygen is passed from the body. Carbon dioxide, the most abundant of these compounds is thrown off at the lungs and has already been shown to be present in respired air. (Experiment, p. 29.)

*The idea has become largely prevalent that the purpose of oxygen is to burn up, or destroy, substances injurious to the body and, in this way, to act as a purifying agent. While it may do this to a limited extent, it is highly misleading to regard this as its chief purpose. In fact, the oxygen of the body serves a purpose quite similar to the oxygen which supports combustion outside of the body. The oxygen in the stove, by uniting with the carbon and hydrogen of the wood, causes the combustion. Instead of uniting only with impurities that may be present in the stove, it unites with the valuable fuel and instead of destroying waste products, it helps to form such waste products as ashes and carbon dioxide.

Carbon Dioxide is a compound of carbon and oxygen and is formed when these substances unite. Its chemical symbol CO_2 indicates one part of carbon and two parts of oxygen. The test for carbon dioxide is lime-water, with which it unites to form carbonate of calcium. By the mixing of lime-water and carbon dioxide a precipitate of calcium carbonate is formed, changing the clear lime-water to a milky white color.

Experiments. 1. (a) Attach a piece of charcoal (carbon) no larger than the end of the thumb to a piece of wire. Ignite the charcoal and lower it into a vessel of oxygen. Observe its combustion. Let it remain until it ceases to burn. Note that in burning, the piece of carbon has diminished in size and the oxygen has disappeared. Has anything been formed in their stead?

(b) Remove the charcoal and add a small amount of lime-water. (See Appendix.) Cover the bottle and bring the gas and lime-water in contact by shaking. Note the change in color of the lime-water. What does this indicate?

2. Burn a splinter in a large vessel of air, keeping the top covered. Add lime-water and shake. Note and account for the result.

3. Place several pieces of limestone (marble) in a fruit or candy jar holding at least one-half gallon. Barely cover the limestone with water and then add hydrochloric acid until a gas is rapidly evolved. This gas is carbon dioxide.

(a) Examine it to see if it possesses color.

(b) Insert a burning splinter and note the result.

(c) Blow a small soap bubble on the end of a tube and disengage it so that it floats on the gas in the jar. (A tube three-eighths of an inch in diameter is best for this purpose.)

(d) Tip the jar over the mouth of the tumbler, as you would in pouring water, though not far enough to spill the acid. Then insert a burning splinter in the tumbler. Result?

Carbon dioxide is a colorless gas which is heavier than air and does not support combustion. It finds its way into the atmosphere as the result of the oxidation of carbon which takes place in combustion, in the decay of animal and vegetable substances, and in the chemical changes which occur in the bodies of animals.

Passage of Carbon Dioxide through the Blood. Part of the carbon dioxide in the blood is dissolved in the plasma and part of it is in loose combination with substances found in the plasma and corpuscles. Its ability to dissolve in liquids, and to enter into chemical combinations, as well, varies with the carbon dioxide tension or pressure. This is greatest at the cells, less in the blood, still less in the lungs, and practically nothing in the outside atmosphere. The conditions, it appears, are just the reverse of those relating to oxygen,

and this accounts for its being taken up at the cells and given off at the lungs.

Final Disposition of Carbon Dioxide. It is readily seen that, if the union of oxygen and carbon continually removes oxygen from the air and replaces it with carbon dioxide, the whole atmosphere will become deficient in the one and have an excess of the other. This condition is prevented through the agency of vegetation. Plants absorb the carbon dioxide from the air, decompose it, build the carbon into compounds that become a part of the plant, and return the oxygen to the air. In doing this, they not only preserve the necessary proportion of oxygen and carbon dioxide in the atmosphere, but also put the carbon and the oxygen in such a condition that they may again unite. The process is carried on in the leaves of plants, but takes place only in the presence of sunlight.

The form in which oxygen enters and leaves the body, as well as its transformation in passing, may be illustrated as follows:

Into a glass tube, six inches in length, place several small lumps of charcoal. Fit in one end of this tube a second small glass tube which is bent at a right angle and made to pass through a close fitting stopper to the bottom of a small bottle. A second small tube is fitted in the stopper, but which terminates near the top of the bottle. The whole arrangement is now such that by sucking air from the top of the bottle it is made to enter the distant end of the tube containing charcoal. Now fill the bottle one-third full of lime-water and heat the tube containing charcoal until it begins to glow. Suck the air through the tube and the bottle, observing what happens at both places. What are the proofs that the oxygen, in passing through the tube, unites with the carbon, forms carbon dioxide, and liberates energy?

Summary. Oxygen, by uniting with the carbon and hydrogen of protoplasm and of food substances, maintains a condition of continuous oxidation at the cells. It enters the body as a free, or uncombined, element and leaves it as a part of the compounds that it helps to form. The free oxygen is transported from the lungs to the cells by means of the haemoglobin of the red corpuscles, while the combined oxygen in carbon dioxide and other compounds is carried from the cells by the plasma. The limited supply of oxygen present in the body at any time makes necessary its continuous introduction into the body.

Review Questions. 1. State the purpose of oxygen in the body. What properties enable it to fulfill this purpose?

2. How does the oxygen entering the body differ from the oxygen leaving the body?

3. What is the necessity for the *continuous* introduction of oxygen into the body, while food is introduced at intervals?

4. How are the red corpuscles able to take on and give off oxygen? How is the plasma able to take up carbon dioxide at the cells and give it off at the lungs?

5. If thirty cubic inches of air pass from the lungs at each expiration and four per cent of this is carbon dioxide, calculate the number of cubic feet of the gas produced in twenty-four hours, the number of respirations being eighteen per minute.

6. What is the weight of this volume, if one cubic foot weighs 1.79 ounces?

7. What portion of this weight is oxygen and what carbon, the ratio by weight of carbon to oxygen being twelve to thirty-two?

8. What is the final disposition of the carbon dioxide in the atmosphere?

CHAPTER VII.

FOODS.

How the Chemical Changes in the Body Differ from those in a Stove. In the preceding chapter, the similarity between the chemical changes in the body and those in a stove was suggested. A closer investigation shows some important differences. The oxidations in the body, which are much slower than those in the stove, are never attended by the production of light and take place at a much lower temperature. Accurately speaking there is no combustion in the body. Another difference of perhaps greater importance is the following: In the stove the action of the oxygen is limited to the fuel, while in the body it unites with the cell protoplasm as well as with what corresponds to the fuel and is called food. In other words, the body itself is consumed by the oxidations. It is necessary, therefore, that both the protoplasm and the food be replaced in the cells and this requires the rapid introduction of new materials into the body.

Purposes of Food. Foods are substances that, on being taken into the normal body, assist in carrying on its work. This definition properly includes oxygen, though the term is usually limited to substances introduced through the digestive organs. Foods serve at least three purposes: 1. They provide materials for rebuilding the tissues. 2. They supply the body with energy.* 3. They render indirect service which is neither that of rebuilding the tissues nor supplying energy, but which is necessary to both processes.

Substances Suitable for Food. It is well known that not all substances which contain materials needed for rebuilding tissues can be used as food. It is also true that many substances which yield energy outside of the body, are unsuited to supplying energy within

* Energy appears in the body chiefly as heat and as mechanical motion. (See Chapter XI.)

the body. In general, materials to serve as food must conform to the following conditions:

1. They must be capable of reduction to a liquid state, or to a finely divided condition, which makes it possible for them to be taken into the body and distributed by the blood to the cells.

2. If they are to build tissue or yield energy they must be capable of oxidation,* that is, they must consist of compounds in which the union of the parts is weak enough to permit of their union with oxygen.

3. Their properties must be such that they yield themselves readily to the body's method of taking up and appropriating new material and they must not injure the tissues.

These conditions limit food substances to a comparatively small number of compounds which are obtained chiefly from the animal and vegetable kingdoms.

Kinds of Food. The different classes of foods are shown by the following table:

1. Nitrogenous substances	{ Proteids.
	{ Albuminoids.
2. Non-nitrogenous substances	{ Carbohydrates { Sugar.
	{ Starch.
	{ Fat. { Solid fat.
	{ Oil.
3. Mineral salts	{ Common salt.
	{ Phosphate of calcium.
	{ Carbonate of calcium.
4. Water.	

While it is essential that foods supply all the chemical elements of the body, there is no simple food, nor class of foods, that contains the whole number. The nitrogenous foods contain carbon, hydrogen, oxygen and *nitrogen*. The non-nitrogenous contain *carbon*, hydrogen and oxygen. The mineral salts contain the other elements of the body.

* These foods are readily oxidized outside of the body as shown by their tendency to decay and the ease with which they may be burned. An interesting experiment is to burn food substances such as sugar, starch, fat, etc., and determine their products of oxidation.

The Proteids form by far the larger and more important class of nitrogenous foods. Different varieties of proteids are represented by *albumin* found in the white of eggs, the lean of meat, and in the plasma of the blood; by *casein* found in milk and cheese; by *gluten* found in grains; and by *legumen* in beans and peas. Since these compounds contain the four chief elements of the body they are made to serve the important purpose of *rebuilding tissues*. As they readily oxidize in the body they also *supply energy*. Their value as food is further increased by the fact that they are easily digested and introduced into the system.

The Albuminoids form a small class of nitrogenous substances which differ from the proteids in being unable to rebuild tissue. The best known example is *gelatine*, a constituent of soup, obtained from bones and connective tissue by boiling. The albuminoids being oxidizable in the body supply energy.

Carbohydrates. The carbohydrate of greatest importance, as a food and also the one found in greatest abundance, is *starch*. All green plants form more or less starch and many of them store it in their leaves, seeds or roots. From these sources it is obtained as food. *Glycogen*, a substance closely resembling starch, is found in the bodies of a few animals, like the oyster, and is manufactured to quite an extent by the liver. Glycogen is sometimes called animal starch. The *sugars* are derived from such plants as sugar-cane and beets, and from fruits. While there are several varieties of sugar, only two are present in any considerable quantity in our foods. These are *sucrose*, or cane-sugar, and *glucose*, or grape-sugar. The former is obtained in large quantities from sugar cane and beets while the latter occurs in ripe *fruits* and in *honey* and is also manufactured from starch.

Composition of Foods. The composition of sucrose is represented by the chemical formula $C_{12}H_{22}O_{11}$, that of glucose by $C_6H_{12}O_6$, and that of starch by $(C_6H_{10}O_5)_n$. Butter, or glyceryl butrate, is $C_3H_5(C_4H_7O_2)_3$ and another variety of fat is $C_3H_5(C_{18}H_{35}O_2)_3$. The exact composition of proteid compounds has never been determined. They are known, however, to be much more complex than the carbohydrates and fats.

Purpose of Non-Nitrogenous Foods. Since these foods do not contain nitrogen, they are unable to supply that element to the protoplasm. For this reason they cannot be used by themselves in rebuilding any tissue except the adipose, and if taken alone they are unable to sustain life. They are, however, readily oxidized in the

body and may be used in relatively large quantities in supplying energy, and this is their chief function. They also protect the nitrogenous substances of the protoplasm from oxidation and, in this way, lessen the quantity of proteid that would otherwise have to be taken. They have a large energy value and their products of oxidation are simple and easily removed from the body. For the simple purpose of supplying energy they are superior to the proteids.

Water finds its way into the body as a pure liquid, as a part of such mixtures as coffee, chocolate, and milk, and as a constituent of all our solid foods. (See table of foods, p. 50.) It is also formed in the body by the uniting of oxygen with the hydrogen. It passes through the body unchanged and is constantly being removed by all the organs of excretion. While water neither builds tissue nor liberates energy, it is as necessary to the maintenance of life as oxygen or proteids. It occurs in all the tissues and forms about two-thirds of the entire weight of the body. Its presence is necessary for the interchange of materials at the cells and for keeping the tissues soft and pliable. P. 27.) As it enters the body it carries digested food substances with it and as it leaves, it is loaded with waste material. Its chief physiological work, which is that of a *transporter of material*, depends upon its ability to dissolve substances and to flow readily from place to place.

The Mineral Salts are found in small quantities in the common articles of diet and, as a rule, find their way into the body unnoticed. They serve a variety of purposes. Phosphate and carbonate of calcium are important constituents of bone, and iron is a necessary part of the haemoglobin of the blood. Others play certain parts in the vital processes. Perhaps the mineral compound of greatest importance is sodium chloride,* or common salt. It is a natural constituent of most of our foods and is also added in the preparation of food for the table. When it is withheld from animals for a considerable length of

* The recently advanced theory that mineral salts, by dissolving in water, separate into their atoms, or other molecular divisions, part of which are charged with positive electricity and part with negative electricity, has suggested several possible uses for sodium chloride and other mineral salts in the body. The sodium chloride in the tissues is in such concentration as to be practically all separated into its sodium and chlorine particles, or ions. Working in line with this theory, Dr. Loeb and his associates, at the University of Chicago, have shown that the sodium ions are necessary for the contraction of the muscles, including the muscles of the heart. There is also reason for believing that different ions may enter into temporary combination with food particles, and in this way play a role in the nutritive processes.

time they suffer intensely and finally die. It is necessary in the blood and lymph to keep their constituents in solution, and it is thought to play an important role in the reaction of protoplasm, especially that of muscle. It is constantly leaving the body as an excretory product and must be constantly supplied in small quantities in the food.

Relative Quantities of the Different Foods. If the proteids are introduced into the body only in the proportion in which they are needed to rebuild tissue, and the energy of the body is obtained chiefly from the carbohydrates and the fats, the ratio of the proteids to the others has been found to be about one to three. That is, for every pound of proteid there will be consumed about three pounds of non-nitrogenous foods. This ratio, however, holds only during health and a condition of moderate exercise. During excessive exercise or in very cold weather there is an increase in the demand for energy food. On the other hand, a condition of convalescence, calls for an increase in the proportion of proteids. Allowance must also be made for constitutional differences in people which cause certain kinds of foods to be more easily digested and assimilated than others.

Food Supply for the Table. The average daily meal should consist of both proteids and non-nitrogenous foods. The former can be obtained from a variety of food-stuffs such as lean meat, eggs, cheese, beans, peas, etc. The latter is supplied by potatoes, rice, butter, white bread, cereals, fat meat, etc. Fruit in some form should be a portion of each meal, as much for its tonic effect on the digestive organs as for what it yields in proteids or carbohydrates. Variety in the supply of food for the table is an essential condition, but need not increase either the work or the expense of supplying food. Each single meal may and should be, simple in itself and still differ sufficiently from the meal preceding and the one following to give the required variety in the course of a day.

Composition of Food-Stuffs. In a very few cases only do the different articles that comprise our daily food represent single proteids or carbohydrates, but most of them are mixtures in which some one food-substance predominates. The following table condensed from Atwater's "Foods: Nutritive Value and Cost," published by the U. S. Department of Agriculture, shows the percentage of proteids, fats,

carbohydrates, water, and mineral salts in the edible portions of the more common substances taken as food:

Food Materials.	Water.	Solids.	Pro- teid.	Fat.	Carbo- hydrates.	Mineral matter.	Fuel value of one pound.
Animal foods, edible portion.							
Beef:	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Calories
Shoulder.....	63.9	36.1	19.5	15.6	.....	1	1,020
Rib.....	48.1	51.9	15.4	35.6	.....	.9	1,790
Sirloin.....	60	40	18.5	20.5	.....	1	1,210
Round.....	68.2	31.8	20.5	10.1	.....	1.2	805
Veal:							
Shoulder.....	65.8	31.2	20.2	9.8	.....	1.2	790
Mutton:							
Shoulder.....	58.6	41.4	18.1	22.4	.....	.9	1,280
Leg.....	61.8	38.2	18.3	19	.....	.9	1,140
Loin.....	49.3	50.7	15	35	.....	.7	1,755
Pork:							
Shoulder roast, fresh.....	50.3	49.7	16	32.8	.....	.9	1,680
Ham, salted, smoked.....	41.5	58.5	16.7	39.1	.....	2.7	1,960
Fat, salted.....	12.1	87.9	.9	82.8	.....	4.2	3,510
Sausage:							
Pork.....	41.5	58.8	13.8	42.8	.....	2.2	2,065
Bologna.....	62.4	37.6	18.8	15.8	.....	3	1,015
Chicken.....	72.2	27.8	24.4	2	.....	1.4	540
Turkey.....	66.2	33.8	23.9	3.7	.....	1.2	810
Eggs.....	73.8	26.2	14.9	10.5	.....	.8	721
Milk.....	87	13	3.6	4	4.7	.7	325
Butter.....	10.5	89	1	85	.5	.3	3,615
Oleomargarine.....	11	89.5	.6	85	.4	.3	3,605
Cheese:							
Full cream.....	30.2	69.8	28.3	35.5	1.8	4.2	2,070
Skim milk.....	41.3	58.7	38.4	6.8	8.9	4.6	1,165
Fish:							
Codfish.....	82.6	17.4	15.8	.4	.....	1.2	310
Salmon.....	63.6	36.4	21.6	13.4	.....	1.4	965
Oysters.....	87.1	12.9	6	1.2	3.7	2	230
Vegetable foods.							
Wheat flour.....	12.5	87.5	11	1.1	74.9	.5	1,645
Graham flour (wheat).....	13.1	86.9	11.7	1.7	71.7	1.8	1,625
Rye flour.....	13.1	86.9	6.7	.8	78.7	.7	1,625
Buckwheat flour.....	14.6	85.4	6.9	1.4	76.1	1	1,605
Oatmeal.....	7.6	92.4	15.1	7.1	68.2	2	1,850
Cornmeal.....	15	85	9.2	3.8	70.6	1.4	1,645
Rice.....	12.4	87.6	7.4	.4	79.4	.4	1,630
Peas.....	12.3	87.7	26.7	1.7	56.4	2.9	1,565
Beans.....	12.6	87.4	23.1	2	59.2	3.1	1,615
Potatoes.....	78.9	21.1	2.1	.1	17.9	1	375
Sweet potatoes.....	71.1	28.9	1.5	.4	26	1	530
Turnips.....	89.4	10.6	1.2	.2	8.2	1	185
Onions.....	87.6	12.4	1.4	.3	10.1	.6	225
String beans.....	73.2	12.8	2.2	.4	9.4	.8	225
Green peas.....	78.1	21.9	4.4	.6	16	.9	405
Green corn.....	81.3	18.7	2.8	1.1	13.2	.6	345
Tomatoes.....	96	4	.8	.4	2.5	.3	80
Cabbage.....	91.9	8.1	2.1	.3	5.5	1.1	155
Apples.....	83.2	16.8	.2	.4	15.9	.3	315
Sugar, granulated.....	2	98	.....	.....	97.8	.2	1,820
Molasses.....	24.6	75.4	.....	.....	73.1	2.3	1,360
White bread (wheat).....	32.3	67.7	8.8	1.7	56.3	.9	1,280
Boston crackers.....	8.3	91.7	10.7	9.9	68.7	2.4	1,895

The Effects of a One-Sided Diet. If an insufficient amount of proteid is supplied to the body, the tissues are improperly nourished and one is unable to exert his normal strength. On the other hand, if

proteids are eaten in excess of the needs of the body, extra work is thrown on the organs of excretion. Sometimes they are unable to remove all the products of proteid oxidation and disorders like gout and certain forms of rheumatism result.

Where it is desirable to supply the table at as small a cost as possible, the vegetable proteids may be used to good advantage. (See table of foods.) While some of these are not so readily digested as meats, they are otherwise just as satisfactory from a hygienic standpoint.

Is Alcohol Suitable for Food? Many people in this and other countries drink in different beverages, such as whiskey, wine, beer, etc., a variable amount of alcohol. This substance has a temporary stimulating, or exciting, effect on the nervous system and the claim has been made that it may serve as food. Recently it has been shown that when alcohol is greatly diluted and introduced into the body in small quantities it is nearly all oxidized and yields energy as does fat or sugar. Still it cannot be said that all substances that can be oxidized are suitable for food. They may possess additional properties which produce harmful effects and this is the case with alcohol. When used in large quantities it injures nearly all the tissues in the body and when taken habitually, even in small doses, "it leads to the formation of the "alcohol habit," which is now recognized as a disease.

While the direct effect of alcohol on the various tissues is not understood, there are certain facts that throw light upon this point. One of these is the action of alcohol upon the proteids of protoplasm and may be illustrated by the following simple

Experiment. Place some of the white of a raw egg in a glass vessel and cover it with a small amount of alcohol. As the albumin hardens, or coagulates, observe that the quantity of clear liquid increases. This is due to the *withdrawal* of water from the albumin by the alcohol. If, instead of pure albumin, some tissue of the animal body, such as a muscle or a part of the liver, were to be used, a similar effect would be produced.

Of course alcohol in the living body is soon diluted and does not produce such marked results. If it did, death would quickly result. However, when the actual changes that do occur in the body by the prolonged use of alcohol, are considered, it seems probable that a similar action may take place in the living tissues, though to a limited degree. (P. 139.)

Instead of being classed as a food, alcohol more properly belongs to a large list of substances which act strongly upon the body to bring

about abnormal and unusual effects. These substances are known by the general name of

Drugs. Drugs embrace a very large number of substances, many of which are used as medicines, but the majority of which, if taken in sufficient quantity, act as poisons. The legitimate and beneficial use of drugs in any individual case can only be determined by a physician. Science sanctions their use only in cases of emergency, where the injurious effects of disease must be counteracted or where the normal activity of the various organs fails temporarily to meet the demands made upon them. Not only are they of no value in health but their use is attended with great danger.

Summary. Materials called foods are introduced into the body for the purpose of rebuilding tissue, supplying energy, and aiding indirectly in the work of the body. The properties of these substances must be such as to adapt them to the body's method of handling materials and they must injure none of the tissues. Only a few classes of substances, viz., proteids, carbohydrates, fats, and some mineral compounds have all the qualities of foods and are suitable for introduction into the body. Substances known as drugs, which may be used as medicines in disease, should be avoided in health.

Review Questions. 1. Give two differences between the chemical changes in the body and those in a stove.

2. What purposes are served in the body by foods?
3. Give the necessary qualities of substances that are suitable for food.
4. Wood and coal contain energy; why can not they be used as food?
5. Why are non-nitrogenous foods taken alone, unsuited for rebuilding tissue?
6. What advantages have the non-nitrogenous over the nitrogenous foods in furnishing energy?
7. Show that life can not be carried on without water.
8. Consulting the table on page 50, select four foods which, if eaten at a single meal, will furnish the correct proportion of tissue building and energy material.
9. What are the proofs that alcohol is not a food?

CHAPTER VIII.

THE ABDOMEN AND ITS CONTENTS.

The entrance of food into the body is effected through the organs of digestion. These, for the most part, occupy the space below the thorax and within the abdomen, called the abdominal cavity. This is a large cavity, holding other organs than the digestive, and ranks in importance with the thoracic cavity. Its general study affords a good introduction to the nature and purpose of the organs that it contains.

Dissection of the Abdomen. For individual study, or for a small class, a *half-grown* cat is perhaps the best specimen available. It should be killed with chloroform and then stretched, face upward, on a board, the feet being secured to hold it in place.

The teacher should make a preliminary examination of the abdomen to see that it is in a fit condition for class study. If the bladder is unnaturally distended, its contents may be forced out by slight pressure.

The following materials will be needed during the dissection and should be kept near at hand: A sharp knife with a good point, a pair of heavy scissors, a vessel of water, some cotton batting or a sponge, and some fine cord.

During the dissection the specimen should be kept as clean as possible. The escaping blood should be mopped up with cotton or a damp sponge. (See Appendix.)

Order of Observations. 1. Cut through the abdominal wall in the center of the triangular space where the ribs converge. From here cut a slit downward to the lower portion of the abdomen and sideward, each way, as far as convenient. Tack the loosened abdominal walls to the board and proceed to study the exposed parts. Observe the muscles in the abdominal walls and the fold of *peritoneum* which forms an apron-like covering over the intestines.

2. Observe the position of the stomach, intestines, liver, and spleen, and then, by pushing the intestines to one side, find the kidneys and the bladder.

3. Trace out the continuity of the food canal. Find the oesophagus, the tube from the mouth, where it penetrates the diaphragm and joins the stomach. Find next the union of the stomach with the small intestine. Then by care-

fully following the coils of the small intestine, discover its union with the large intestine.

4. Study the liver with reference to location, size, shape, and color. On the underside, find the gall bladder from which a small tube leads to the small intestine. Observe the *portal vein* as it passes into the liver. As the liver is surcharged with blood, care must be taken to prevent cutting it, or its connecting blood vessels.

5. Within the first coil of the small intestine as it leaves the stomach find the *pancreas*. Note its color, size, and branches. Find where it connects with the small intestine.

6. Beginning at the cut portion of the abdominal wall, lift the thin lining, called the *peritoneum*, and carefully follow it toward the back and central portion of the abdomen. Observe whether it extends back or in front of the kidneys, the aorta, and the vena cava. Find where the right and left portions unite to form a rather heavy double membrane, the *mesentery*, which passes from the posterior abdominal wall and surrounds and holds in place the large and small intestines.

7. Tie the canal tightly in two places, half an inch apart, above the stomach and cut it in two between these places. Likewise tie and cut the rectum. The stomach and intestines may now be removed from the abdominal cavity and studied to better advantage. Examine the *mesentery* and its connection with the intestines. Notice the divisions of the portal vein and the *lacteals* passing through it. Sketch a coil of the intestines and the mesentery attached to it.

8. Find in the center of the coils of the small intestine an elongated, gland-like body. This is the beginning of the *thoracic duct* and is called the *receptacle of the chyle*. From this the thoracic duct rapidly narrows until it becomes difficult to trace in a small animal.

9. Cut away about two inches of small intestine from the remainder. Split it open for a part of its length and wash out its contents. Observe its coats. Place in water and examine the mucous membrane with a lens to find the villi.

10. Study the connection of the small intestine with the large; split it open at this place, wash out contents, and examine the ileo-coecal valve.

11. Observe the size, shape, and position of the kidneys. Do they lie in front or back of the peritoneum? Do they lie exactly opposite each other?

12. Note the connection of each kidney with the aorta and inferior vena cava by the renal artery and renal vein. Find a slender tube, the *ureter*, running from each kidney to the bladder. Do the ureters connect with the top or base of the bladder? Show by a sketch the connection of the kidneys with the large blood vessels and the bladder.

The Abdominal Cavity lies immediately below the cavity of the thorax and is separated from it by the diaphragm. Its surrounding walls are continuous with those of the thorax, but are less resisting and admit of greater freedom of motion. The spinal column and muscles of the loins form a heavy, supporting structure at the back, while the sides and front are made up mainly of connective tissue and

sheets of muscle. The cavity terminates below in the hollowed-out portion of the pelvic bones. These join firmly with the spinal column behind and provide suitable projections for the attachment of the muscular walls in the front and at the sides.

Location of Abdominal Organs. The general form and arrangement of the abdominal organs in man are similar to that of the animal dissected. The space immediately below the diaphragm is occupied by the liver and stomach, the liver being chiefly on the right side and the stomach on the left. The central portion of the cavity is occupied by the small intestine. This is so coiled that a narrow space is left between it and the right and left abdominal walls and also between it and the stomach. The large intestine occupies this space and, in so doing, almost completely encircles the coil of small intestine. To the left and a little below the stomach is the spleen. The kidneys lie against the posterior abdominal wall, on either side, slightly above the middle, while the bladder occupies the central lower portion of the cavity.

The Peritoneum, the lining membrane of the abdominal cavity, has the same general arrangement as the pleura in the cavity of the

thorax. It forms a continuous lining for the walls of the cavity, including the diaphragm above and the pelvic basin below, and forms an outside covering to all the organs in the cavity except the kidneys and the bladder. It is the most extensive serous membrane of the body. The part extending from the spinal column to the large and small intestines, is called the *mesentery*. It appears as a thin, transparent membrane, containing

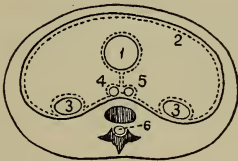


Fig. 16. Relations of the peritoneum. 1. Food canal. 2. Peritoneum. 3. Kidneys. 4. Inferior vena cava. 5. Aorta. 6. Spinal cord. The position of the peritoneum is indicated by the dotted line.

blood and lymph vessels, and surrounds and supports the intestines as an arm is supported in a sling. Friction is prevented in the movements of the abdominal organs by the *peritoneal fluid* which is secreted in small quantities. Fig. 16.

The Abdominal Walls, except at the back, are rather thin and flexible and permit freedom of motion in the bending and twisting of the trunk. This is the more necessary at this part of the body since the arrangement of the ribs is such that the upper part of the trunk is

more or less rigid. The muscles in the walls cause various movements of the trunk while the long muscular band which extends vertically over the front of the abdomen, called the *abdominis rectus*, is able by contraction to diminish the size of the abdominal cavity. The pressure which it is able to exert may be transmitted to the underside of the diaphragm, to aid in expelling the air from the lungs. (P. 36.)

Hygiene. While the clothing around the waist may be snug and close-fitting, it should never be of a nature to interfere with the freedom of the abdominal movements. Tight lacing, if long continued, weakens the abdominal walls, breaks down the natural thoracic arch, and deforms and displaces such important organs as the liver and the stomach. The imaginary gain in beauty of form, by such practice, is more than counterbalanced by loss of grace and ease of motion, to say nothing of the liability of injury to the health.

Summary. The abdomen provides a suitable cavity for holding the digestive and other important organs. Its walls are muscular and pliable, yield readily in the different movements of the trunk, and render indirect aid in the process of respiration.

Review Questions. 1. What cavities are found in the trunk? Name the important organs in each.

2. Compare the pleura and the peritoneum with reference to structure, general arrangement, and function.

3. Give the function of the abdominal muscles and the diaphragm.

4. How are the abdominal walls held in position?

5. What changes in the abdomen take place during respiration? Why are these changes necessary?

6. Draw a curved line to represent the general shape of the abdominal cavity and indicate within it the position of the stomach, liver, spleen, kidneys, and bladder.

CHAPTER IX.

DIGESTION.

Digestion is the process by which food materials are prepared for the blood. Since only liquids and dialyzable materials can enter the blood vessels, digestion must consist, to a large extent in changing solids into liquids and in converting non-dialyzable into dialyzable* substances. The process is partly mechanical and partly chemical and may be imitated to some extent by dissolving substances in liquids.

Experiment. To a tumbler two-thirds full of water add a little salt. Stir and observe the effect of the water on the salt. Taste the solution to see that the salt has not been changed chemically. Now add a small bit of lime and stir as before. Observe that while the lime may be separated into smaller pieces it does not dissolve. Now add some hydrochloric acid and stir as before, noting the result.

In this experiment we are concerned with (1) water which is already a liquid, (2) salt which becomes a liquid by dissolving in water, (3) lime, or calcium hydroxide, which is practically insoluble in water but dissolves when hydrochloric acid is added. The acid simply changes the insoluble calcium hydroxide into soluble calcium chloride which the water then dissolves. (4) Finally we note that a vessel, or container, is used to hold the materials concerned in the experiment.

In the digestion of the food similar conditions are provided by the organs concerned.

Digestibility of Foods. With reference to the changes they undergo during digestion, foods may be divided into three classes:

1. Substances already in the liquid state. Water is the chief substance belonging to this class. Oils used for food and milk are exceptions.

2. Foods soluble in water. This class includes several mineral substances and grape sugar. These require simply to be dissolved.

* Dialyzable materials are those that can pass, when in solution, through animal membranes. (See experiment, page 27.)

3. Foods that are insoluble in water. The greater number of the solid foods, including proteids, starch, and fats, belong to this class. Their digestion consists in changing them into substances that are soluble in water.

The Organs of Digestion are of three kinds: 1. Those for crushing and grinding the food. 2. Glands that secrete liquids which act upon the food to change it chemically and dissolve it. 3. Cavities in which the different processes of digestion take place and tubes connecting them.

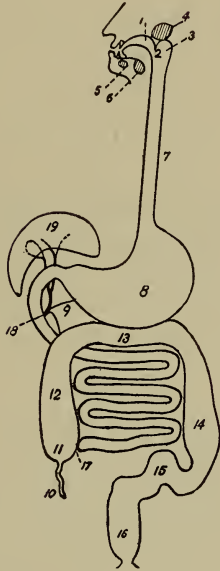
The different cavities and the tubes are connected to form one continuous passageway which, beginning at the mouth and extending entirely through the body, forms the *alimentary canal*. The parts of this canal and the glands which aid in digestion are shown by the following table:

Digestive Organs	Parts of Alimentary Canal	{ Mouth Pharynx Oesophagus Stomach Intestines...	{ Small. { Duodenum Jejunum Ileum Large. { Coecum and vermiform appendix Colon..... { Ascending Transverse Descending Sigmoid flexure Rectum
	Digestive Glands.....	{ Salivary.... { Parotid Gastric { Submaxillary Liver { Sublingual Pancreas Intestinal	

The Alimentary Canal varies in length in different individuals from 25 to 30 feet. Its parts present such differences as adapt them to their particular work although a general similarity of structure prevails. Its walls, except at the mouth, are distinct from the surrounding tissues and consist, for the most part, of separate layers or coats, as follows: 1. The first coat, or lining, consists of mucous membrane and is named from a liquid which it secretes, called mucus. This membrane is not limited to the alimentary canal but lines all the cavities of the body to which air has access. Since it is continuous with the skin, where these cavities open at the surface of the body, it is sometimes called the "inner skin." It resembles the skin in structure, being made up of two layers—a thick under-layer which

contains blood vessels, nerves and glands, and a thin surface layer of epithelial cells.

2. The second, or middle, coat is muscular and forms a continuous layer throughout the canal, except at the mouth. Here its place is taken by the strong muscles of mastication which are separate and distinct from each other. As a rule this muscle belongs to the non-striated, or involuntary, type and consists of two layers that surround the canal as sheets or bands. In the inner layer the fibers encircle the canal, but in the outer layer they are arranged longitudinally.



3. The third, or outer, coat surrounds and is limited to those portions of the canal that occupy the cavity of the abdomen. This coat is a continuation of the lining membrane of the cavity, called the peritoneum. (P. 55.)

Another coat called the *submucous* which lies between the mucous and the muscular is frequently described.

The Digestive Glands, sometimes described as accessory organs of digestion, are either situated in the mucous membrane of the canal or are

Fig. 17. Diagram of the digestive system. 1. Mouth. 2. Soft palate. 3. Pharynx. 4. Parotid gland. 5. Sublingual gland. 6. Sub-maxillary gland. 7. Oesophagus. 8. Stomach. 9. Pancreas. 10. Vermiform appendix. 11. Coecum. 12. Ascending colon. 13. Transverse colon. 14. Descending colon. 15. Sigmoid flexure. 16. Rectum. 17. Ileo-coecal valve. The position and connections, not the relative length, of the small intestine are shown in the figure.

located at convenient places and connect with the canal by tubes, called ducts. They manufacture their secretions from materials which they derive from the blood and empty them into the canal where they can act on the food.

The Digestive Processes. Digestion is accomplished by acting upon the food in different ways, as it is passed along the canal, with

the final purpose of reducing it to a liquid and dialyzable condition. Several distinct processes are necessary and they occur in such an order that those preceding are preparatory to those that follow. These processes are mastication, insalivation, deglutition, stomach digestion, and intestinal digestion and they take place in the order named. As the different materials become liquified they are transferred to the blood by a special process known as absorption. Substances not reducible to the liquid state pass on through the canal as waste.

The Mouth is an oval-shaped cavity situated at the very beginning of the canal. It is surrounded by the lips in front, the cheeks on the sides, the soft palate behind, the hard palate above, and the tissues of the lower jaw below. The mucous membrane lining the mouth is soft and smooth being covered with flat epithelial cells. The external opening of the mouth is guarded by the lips while the soft palate forms a movable partition between the mouth and the pharynx. In a condition of repose the mouth space is all taken up by the tongue and the teeth; but the cavity may be increased and room provided for food by depressing the lower jaw. The mouth by its construction is adapted to carrying on the processes of

Mastication and Insalivation. Mastication is the process by which solid food is reduced, by the cutting and grinding action of the teeth, to a finely divided condition. Insalivation is the process of mixing the food with saliva. Both processes take place at the same time and are accomplished, in part, by the same agencies. The saliva dissolves the soluble portions of the food, softens and lubricates portions that it cannot dissolve, and acts chemically upon the starch, changing it into a form of sugar. The main purpose of both mastication and insalivation is to prepare the food for the processes that are to follow.

Experiments. 1. Fill two tumblers each half full of water. Into one place a lump of rock salt. Into the other place an equal amount of salt that has been pulverized. Which dissolves first? Why?

2. Hold in the mouth for one or two minutes a small piece of red litmus paper. Note and account for change in color. (The turning of red litmus blue indicates an alkaline condition of the mouth.)

3. Prepare starch paste by mixing one-half of a teaspoonful of starch in half a pint of cold water and bringing it to a boil. Place some of this in a test tube and thin it by adding more water. Then add a small drop of a solution made by dissolving iodine in alcohol. It should turn a deep blue color. This is the test for starch. Now collect from the mouth, in a clean test tube, two or three tea-

spoonfuls of saliva. Add portions of this to small amounts of fresh starch solution in two test tubes. Let the tubes stand for five or ten minutes surrounded by water, having about the temperature of the body. Test for changes that have occurred as follows:

(a) To one tube add a little of the iodine solution. If it does not turn blue, it shows that the starch has been changed into something else by the saliva. (b) To the other tube, add a few drops each of a solution of potassium hydroxide and of copper sulphate and boil the mixture. If it turns an orange red color, the presence of sugar is proven.

4. Hold a little starch in the mouth until it is completely dissolved and observe that it gradually gives a sweetish taste.

The chemical action of saliva is due to an active agent that it contains, called *ptyalin*. This acts best in the liquids that are slightly alkaline.

Accessory Organs of the Mouth. The work of mastication and insalivation is accomplished through organs situated within and around the cavity of the mouth. These comprise:

1. *The teeth*, which are set in two rows, one immediately over the other, in the upper and lower jaws, with their hardened surfaces facing. In reducing the food the lower jaw moves against the upper. The upper and lower front teeth, which are flat and chisel shaped, do not meet squarely, but their edges glide over each other, like the blades of scissors, a condition that adapts them to cutting off and separating portions of food. The back teeth are broad and irregular and are adapted to crushing and grinding the food.

2. *The tongue*. This is a muscular organ whose fibers extend in several directions. This accounts for the great variety of movements which it is able to perform. Its chief work during mastication is to transfer the food from one part of the mouth to another and, with the aid of the cheeks, to keep the food between the rows of teeth. But it has functions in addition to these and is, altogether, a most useful organ.

3. *The muscles of mastication*. These are attached to the lower jaw and bring about its different movements.

4. *The salivary glands*, which are situated in the tissues surrounding the mouth and communicate with it by means of ducts. These are six in number and are arranged in three pairs. The largest, called the parotid glands, lie, one on each side, in front of and below the ear. The next in size, the submaxillary, are located, one on each side, just below and in front of the triangular bend in the lower jaw. The smallest, the sublingual glands, are situated in the floor of the mouth, one on either side of the base of the tongue.

(For more complete descriptions of the accessory organs of the mouth, the student is referred to some work on anatomy.)

Deglutition, or swallowing, is the process by which the food is transferred from the mouth to the stomach. While it is not, strictly speaking, a digestive process, it is nevertheless necessary to the further digestion of the food. The chief organs concerned in deglutition are the tongue, the pharynx, and the oesophagus.

The Pharynx is a rounded sac-like body lying immediately back of the nostrils, mouth, and larynx. It is somewhat funnel-shaped and extends from the under portion of the skull to where it joins the oesophagus. It has a length of about four and one-half inches and communicates with other parts of the body by seven separate openings. One of these is with the mouth, one with the oesophagus, one with the larynx, one with each of the nostrils and one with each of the middle ears. (Fig. 11, p. 31.) The pharynx is the part of the food canal that is crossed by the air passage and its upper portion properly belongs to the system of air tubes. Within the walls of the pharynx is a series of over-lapping muscles which, by their contractions, draw its sides together and diminish the cavity.

The Oesophagus, or gullet, is a tube eight or nine inches in length that connects the pharynx with the stomach. It lies for the greater part of its length in the thoracic cavity. It consists chiefly of a mucous lining surrounded by a heavy coat of muscle.

Steps in Deglutition. 1. By the contraction of the cheek muscles, the food ball, or bolus, is pressed into the center of the mouth and upon the upper surface of the tongue. Then the tongue, by an upward and backward movement, pushes the food under the soft palate and into the pharynx.

2. As the food passes into the pharynx, the soft palate is pushed backward and upward, closing the opening of the pharynx above, while the pressure of the food on the epiglottis (p. 31) causes that body to close the opening into the larynx. In this way all communication between the food and air passage is temporarily closed. The upper muscles of the pharynx now contract upon the food, forcing it downward, and into the oesophagus.

3. In the oesophagus the food is forced along by the successive contractions of the muscles above until the stomach is reached.

The Stomach is the largest dilatation of the alimentary canal. It is situated in the abdominal cavity, immediately below the diaphragm, with the greater portion on the left side. It connects with the oesophagus at the upper, or *cardiac*, end and with the small intestine at its lower, or *pyloric*, extremity. It varies greatly in size in different individuals being on an average from ten to twelve inches at its greatest length, four to five inches at its greatest width, and holding when full, from three to five pints. It has the coats common to all parts of the canal, but with such modifications as adapt it to its special work. The muscular coat consists of three separate layers, which are named, from the direction of their fibers, the circular layer, the longitudinal layer, and the oblique layer. The circular layer becomes quite thick at the pyloric orifice, forming a distinct band which serves as a valve.

The mucous membrane is thick and highly developed, containing great numbers of small granular bodies known as the gastric glands. These are of two general kinds and secrete in large quantities a liquid, called gastric juice. When the stomach is only partly filled, the mucous membrane is thrown into folds which extend in a longitudinal direction. These disappear, however, when the walls of the stomach are distended with food.

Stomach Digestion is largely a chemical process and is due to the action of the gastric juice. This is a thin, colorless liquid which is composed chiefly of water. But dissolved in the water are several mineral salts and three active agents—hydrochloric acid, pepsin, and rennin. The chief action of the gastric juice is upon the proteids. These substances, being insoluble in water, are changed into two soluble substances, known as proteoses and peptones. The chief agent in bringing about this change is the pepsin which acts as an enzyme, or ferment. (Chap. 10.) The pepsin, however, is able to act only in an acid medium—a condition furnished by the hydrochloric acid.

Experiment. After washing out the stomach of a recently killed pig, scrape off the mucous coat and mince it fine. Mix with some dilute hydrochloric acid (two per cent solution) and keep for a few hours in a warm place. Strain off the liquid. It will digest proteids, like normal gastric juice, although it contains impurities and decomposes on standing. To such a liquid add some boiled white of egg, finely minced, or some shreds of fibrin obtained from coagulated blood. Keep in a warm place for an hour or so and note the results.

An artificial gastric juice which also gives good results in this experiment,

may be prepared by adding scale pepsin, obtained from a drug store, to a two per cent solution of hydrochloric acid.

The digestion of the starch which began in the mouth is checked in the stomach. This is because the ptyalin of the saliva, does not act in an acid medium. While there is no appreciable action on the fat itself, the proteid membranes that inclose the fat particles, are dissolved away and the particles of fat are set free.

The muscular layers, by alternately contracting and relaxing, mix the food with the gastric juice. The muscular band at the pyloric orifice remains contracted, keeping the opening into the small intestine closed, except at intervals, when it relaxes and allows materials to be forced from the stomach.

In addition to carrying on a process of digestion, the stomach also serves as a necessary receptacle, similar in purpose to the hopper of certain machines, in which the food may be accumulated and from which it is gradually passed into the small intestine.

The Small Intestine is a coiled tube, about twenty-two feet in length, which occupies the central and lower part of the abdominal cavity. At its upper extremity it connects with the pyloric end of the stomach and at its lower end it joins the large intestine. It averages a little over an inch in diameter and gradually diminishes in size from the stomach to the large intestine. The first eight or ten inches form a short curve that is separated from the main coil and is called the *duodenum*. The upper two-fifths of the remainder is called the *jejunum* and the lower three-fifths is known as the *ileum*. The ileum joins that part of the large intestine known as the *coecum* and at their place of union is a marked constriction, called the *ileo-coecal* valve. Fig. 17. The muscular coat is made up of a layer of circular and a layer of longitudinal fibers. The mucous membrane is thrown into many transverse, or circular, folds which greatly increase its surface, and is covered with great numbers of minute elevations, known as the villi. It is richly supplied with blood vessels and contains many small glands that secrete a liquid, called the intestinal juice. Most of the liquid, however, used in the small intestine, is poured into it by two large glands, the liver and the pancreas, that connect with it by ducts.

The Liver is situated immediately below the diaphragm on the right side and is the largest gland in the body. It weighs about four

pounds and is separated into two main divisions, or lobes. It has a complex structure and differs from the other glands in several particulars. It receives blood from two distinct sources—the portal vein and the hepatic artery. The portal vein carries the blood in its return flow from the stomach, intestines, and spleen. It is loaded with food materials, but contains little or no oxygen. The hepatic artery, branching from the aorta, carries blood containing oxygen. In the liver the portal vein and the hepatic artery divide and subdivide until they empty into a single system of capillaries surrounding the liver cells. The capillaries in turn empty into a single system of veins which unite to form the large hepatic vein. This empties into the inferior vena cava.

The liver is more or less active at all times and secretes daily two or three pounds of a yellowish, alkaline liquid called *bile*. On its under side is a small membranous sac which serves as a reservoir for the bile and is called the *gall bladder*. The bile passes from the gall bladder and from the right and left lobes of the liver by three separate ducts which unite to form a common tube which, blending with the duct from the pancreas, empties into the duodenum. Though usually described as an organ of digestion, the liver has other functions of equal or greater importance. (Pages 73 and 88.)

The Pancreas is a tapering and somewhat wedge-shaped gland and is so situated that its larger extremity or head is encircled by the duodenum. From here the more slender portion extends across the abdominal cavity nearly parallel to and behind the lower part of the stomach. It has a length of six or eight inches and weighs from two to three and one-half ounces. Its secretion, the pancreatic juice, is emptied into the duodenum by a duct which, as a rule, blends with the duct from the liver.

Intestinal Digestion. The bile partakes more of the nature of a waste product than of a digestive fluid. However, it possesses properties that enable it to be utilized in the food canal in a variety of ways:

1. Since it is alkaline, it counteracts the acid of the stomach, producing an alkaline condition which is necessary for the action of the pancreatic juice.

2. It increases the peristaltic action of the intestines by acting as a stimulus to the muscular coat.

3. It is an antiseptic substance and retards the decomposition of food in the intestines.

4. It furnishes a large bulk of liquid which helps to move the contents of the intestines along.

5. It probably assists in the digestion of the fats.

The principal constituents of pancreatic juice are water, salts, and three different enzymes, or ferments—trypsin, amylopsin, and steapsin. These constituents make pancreatic juice the most important of the digestive fluids. It acts vigorously on all classes of foods.

1. It changes starch into sugar, completing the work begun by the saliva. This action is due to the amylopsin which is similar to pyalin, but is more vigorous.

2. It changes proteids into proteoses and peptones, completing the work of the gastric juice. This is accomplished by the trypsin which is similar to, but more active than the pepsin.

3. It is the chief agent in the digestion of fat. In this work the active agent is the steapsin.

Experiments. 1. Prepare artificial pancreatic juice by chopping fine the pancreas of a recently killed pig and soaking it in a one per cent solution of sodium carbonate in water. After some hours, strain off the liquid which is then ready for use. Add some of this liquid to a thin solution of starch paste, prepared as in a previous experiment, and keep in a warm place for five or ten minutes. Note change in appearance and test for presence of sugar with potassium hydroxide and copper sulphate. (Page 61.)

2. Mince a piece of the white of a boiled egg and add to it a considerable amount of the solution from the pancreas. Keep for a few hours in a warm place and examine.

Extract of the pancreas, obtained from the drug store, may be substituted in this experiment for the fresh specimen.

The intestinal juice assists in bringing about an alkaline condition in the small intestine and probably aids in reducing cane sugar to glucose. It is secreted only in small quantities.

Digestion of Fat. Several different theories have been proposed regarding the digestion and absorption of fat. Among these, what is known as the "solution theory" seems to have the greatest amount of evidence in its favor. According to this theory, the fat, under the influence of the steapsin, absorbs water and splits into fatty acid and glycerine. This finishes the process so far as the glycerine is concerned as it is soluble in water, but the fatty acid which is insoluble in water requires further treatment. It is supposed to be acted

upon in one, or both, of the following ways: 1. To be dissolved as fatty acid by the action of the bile (since bile is capable of dissolving it under certain conditions). 2. To be combined with sodium carbonate and converted into soluble soap.

The emulsion of fat, by which it is separated into minute particles but not changed chemically, is known to occur in the intestine. This process, according to the solution theory, is not one of digestion, but a process which accompanies and aids in the conversion of fat into glycerine and fatty acid.

Work of the Small Intestine. The small intestine is probably the most important division of the alimentary canal. It serves as a contrivance for holding the food while it is being acted upon; it secretes the intestinal juice, mixes the food with the digestive fluids, propels it toward the large intestine, and, in addition, serves as an organ of absorption.

Digestion is practically accomplished in the small intestine and the greater portion of the reduced food is here absorbed. There is always present, however, a variable amount of material that is not digested. This, together with a considerable volume of liquid, is passed into the large intestine.

Work of the Large Intestine. The large intestine serves as a receptacle of materials from the small intestine. The digestive fluids continue their action on the food and the digested materials also continue to be absorbed. In these respects the work of the large intestine is similar to that of the small. It does, however, a work peculiar to itself in that it collects and retains undigested food particles, together with other waste, and ejects them periodically from the canal.

The large intestine is from five to six feet in length and averages about one and one-half inches in diameter. Its divisions are shown in figure 17.

Work of the Alimentary Muscles. The mechanical part of digestion is performed by the muscles which encircle the canal. Their chief uses, which have been mentioned in connection with the different organs, may here be summarized: 1. They supply the force necessary for the mastication of the food. 2. They propel the food through the canal. 3. They mix the food with the different juices. 4. At certain places like the pyloric end of the stomach they partly, or completely, close the passage until a process of digestion is completed.

Health Suggestions. The following simple rules are familiar to nearly everybody and their purpose generally understood: 1. Eat slowly and masticate the food thoroughly. 2. Avoid eating between meals. 3. Drink sparingly of liquids during meals. 4. Never swallow large particles of food, that are not well masticated. 5. Obey your natural appetite and do not think too much about what you eat or drink.

Dangers from Impure Food. Food is frequently the carrier of disease germs and for this reason requires close inspection. Typhoid fever generally finds its way into the body through impure water. Heat is destructive to disease germs, or bacteria, and one safeguard against questionable food is thorough cooking. Too much care cannot be exercised with reference to water for drinking purposes. Water which is not perfectly clear, which has an odor, or which forms a sediment on standing, is not fit to drink. It can be rendered comparatively harmless, however, by boiling for some time. When this is done it should be boiled the day before it is used in order to give it a chance to cool, settle, and take up new air.

Care of the Bowels. Frequently, through lack of exercise or through negligence in evacuating the bowels, a weakened condition of the muscles of the food canal is induced that results in the retention of waste beyond the time when it should be discharged. This is a great annoyance and, at the same time, a menace to health. In addition to the irritating effects of the retained material, waste products are reabsorbed into the system and circulated over the body by the blood. In most cases this condition can be relieved and prevented from recurring by observing the following habits: 1. Have a regular time each day for evacuating the bowels. 2. Drink a cup of cold water on rising in the morning. 3. Eat generously of fruits and coarse foods such as oatmeal, corn bread, etc. 4. Persistently practice such exercises as bring the abdominal muscles into play.

Do not rely upon patent medicines, pills, etc., as they usually leave the canal in a weakened condition. When in need of help consult a physician.

Effect of Beverages. Alcoholic beverages when taken in any but very small quantities, have an injurious effect upon the stomach and the liver. Tea and coffee, while they may exert beneficial effects in small quantities, are liable to interfere with the digestive processes if taken in large quantities.

Summary. By digestion, food substances are reduced to such a condition that they may be introduced into the circulation. While a few substances need simply to be dissolved, most foods must be converted into substances that are soluble and dialyzable. Digestion, therefore, is, to a large extent, a chemical process. The digestive fluids supply water, which acts as a solvent and carries important active agents, called enzymes, that accelerate the changes. The alimentary muscles perform the mechanical work of digestion, while the nervous system controls and co-ordinates the various organs.

Review Questions. 1. State the purpose of digestion. How does digested food differ from that not digested?

2. Name the different classes of food that must be reduced to soluble substances in the process of digestion.

3. Name the divisions of the canal in the order that the food passes through them.

4. What is gained by mastication? Why should this process precede the others?

5. What is the work of the tongue in digestion?

6. Why should a weakness of the muscular coat interfere with the digestive processes?

7. Describe the work of the stomach.

8. Give reasons for regarding the small intestine the most important division of the food canal.

9. At what place and by the action of what liquids are fats, proteids, starch, and cane sugar digested?

CHAPTER X.

ABSORPTION, STORAGE, AND ASSIMILATION.

Digested food to reach the cells must first be transferred to the blood stream. The process is known as *absorption*. In general, absorption means the penetration of a liquid into the pores of a solid, and takes place according to the simple laws of molecular movements. Physiological absorption is, however, not a simple process, since other than molecular forces are involved and the passage takes place through an *active* (living) membrane. Another difference is that certain foods undergo chemical change while being absorbed.

The Small Intestine as an Organ of Absorption. While absorption may occur to a greater or less extent along the entire length of the alimentary canal, most of it takes place in the small intestine. Its great length, its small diameter, and its blood vessels all adapt the small intestine to the work of absorption. The transverse folds in the mucous membrane, by retarding the food in its passage and by increasing the surface, also aid in the process. Of greater importance, however, are the minute elevations that cover the surface of the mucous membrane, known as

The Villi. Each single elevation, or villus, is about one-fiftieth of an inch long, has a diameter about half as great, and contains the following essential parts: 1. An outer layer of epithelial cells, resting upon a connective tissue support. 2. A small lymph tube which occupies the center and connects at the base with other lymph tubes, called *lacteals*. 3. A network of capillaries. Fig. 18.

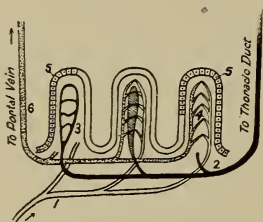


Fig. 18. Structure of the villi. 1. Small artery. 2. A lacteal. 3. Terminal lymph tube. 4. Capillaries. 5. Epithelial cells. 6. Small vein.

The villi are the only structures that are especially adapted to the work of absorption and they are found only in the small intestine. The mucous membrane, however, in all parts of the canal, is capable of taking up more or less of the digested materials.

The Capillaries and Lacteals act as receivers of material as it passes through the layer of epithelial cells covering the mucous membrane. The lacteals take up only the digested fat, while the capillaries receive all the other kinds of food. From their terminals in the villi, the lacteals extend through the mesentery and connect with the thoracic duct. They are called lacteals because of their milk-like appearance, given them by the absorbed fat.

The capillaries in the mucous membrane of the small intestine and other parts of the canal, empty into small veins that unite with the branches of the portal vein, through which the blood is passed to the liver.

Passage of Different Materials through the Epithelial Layer. The layer of epithelial cells, lining the mucous membrane, separates the contents of the alimentary canal from the fluids of the body proper. It serves both as a membrane through which osmosis may take place and as an active agent in bringing about chemical changes in the substances as they pass through. These changes are necessary in the economy of the body and vary with the different foods, as follows:

The Carbohydrates which, during digestion, were changed into maltose and the different forms of glucose, are, by absorption, changed into the form of glucose known as *dextrose*.

The proteids which were changed into proteoses and peptones are converted into the proteids of the blood, the chief of which is serum albumin.*

The fat which was changed into glycerine, fatty acid and soluble soap, is formed again into fat by the union of the glycerine with the fatty acid and the soluble soap.

Water which has undergone no change in digestion, undergoes no change in absorption. Its passage takes place, as far as can be discovered, according to the laws of osmosis and the greater portion of it is absorbed from the small intestine.

The salts are thought to be absorbed according to osmotic laws and to undergo no change in their passage through the epithelial layer. It is possible, however, that the protoplasm of the epithelial cells influences their passage.

* The necessity for this change is proven by the fact that proteoses and peptones when injected into the blood as such act as poisons.

Routes to the Circulation. The absorbed material does not find its way at once into the general circulation, but is conducted by special channels, or routes, to places where it can be admitted most advantageously. There are two such routes—one is that taken by the fat; the other is the one taken by all the remaining food substances. Fig. 19.

1. *Route taken by the fat.* The fat entering the villi from the intestinal canal, finds its way into the lacteals and by them is conveyed

to the *receptacle of the chyle*. At this place the fat mingles with the lymph from the lower part of the body and with it passes through the thoracic duct to the left subclavian vein. Thus, to reach the general circulation, the fat must pass through the villi, lacteals, receptacle of the chyle, and the thoracic duct. Its passage through these places, like the movements in all lymph vessels, is quite slow and it is only gradually admitted to the blood stream.

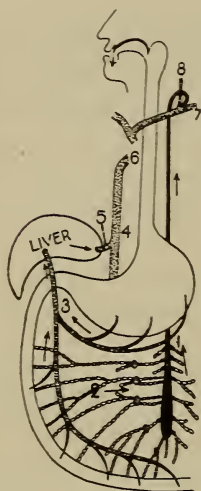


Fig. 19. Routes to the circulation. 1. Receptacle of chyle. 2. Lacteals. 3. Portal vein. 4. Inferior vena cava. 5. Hepatic vein. 6. Position of heart. 7. Left sub-clavian vein. 8. Left jugular vein.

2. *Route of all substances except fat.* Water, salts, carbohydrates, and proteids, in passing through the layer of epithelial cells, enter the capillaries. Here they mix at once with the blood and in a sense are already in the general circulation. But this blood is passed through the portal vein to the liver. Here it enters a second set of capillaries and, by them, is brought

very near the liver cells. After undergoing important changes in the liver it passes through the hepatic vein into the inferior vena cava. This route then, includes the capillaries in the mucous membrane, branches of the portal vein, the portal vein proper, the liver, and the hepatic vein. In passing through the liver a large portion of the food material is temporarily retained for a purpose and in a manner now to be explained.

Storage of Nutriment. The rapid absorption which takes place at the alimentary canal, at intervals corresponding to the taking of food, introduces into the body proper, food materials faster than the cells can make use of them. Following these intervals are periods when the body is taking no food but during which the cells must be supplied with nutriment. It also happens that the total food absorbed during a prolonged interval may be in excess of the needs of the cells during that time, while it is always possible, as in disease, to encounter conditions when the material absorbed does not equal that consumed. To keep up a uniform supply of material for the cells and to provide for emergencies, it is necessary that the body accumulate food materials in excess of its immediate needs.

The Method of Storage differs with the various food substances as follows:

1. *The carbohydrates* are found chiefly in three places in the body,—the blood, the muscles, and the liver. That in the blood is mostly in the form of dissolved dextrose and is ready for use. That in the muscles and liver is in the form of glycogen—the form in which carbohydrates are stored. It is one of the functions of the liver to collect the dextrose from the blood, to change it to glycogen, and to retain it until needed by the cells. There is always present in the blood a small amount of dextrose, and as this quantity is drawn upon by the cells, the glycogen in the liver changes back to dextrose, dissolves, and flows out into the blood. The glycogen in the muscles is in small quantities and is consumed by the muscle cells as occasion demands. Another method of storing the carbohydrates is that of converting them into fats.

2. *The fat* which is awaiting oxidation in the body may be found either in the blood plasma or distributed among the various tissues. Certain of the connective cells possess the property of taking up the fat from the blood and of depositing it in their protoplasm. When this is done to excess and the cells become filled with fat they form adipose tissue. This tissue is found chiefly under the skin and in places where it fills out inequalities. The fat in the blood is in small quantities, except for a time after each period of digestion, when the quantity is somewhat increased.

3. *The proteids* form a part of all the tissues of the body and for this reason are accumulated in larger quantities than any of the other food substances. They are also found in relatively large quan-

tities in the blood, where they are designated "circulating proteids." When eaten in excess, proteids may also be converted, in part, to glycogen at the liver. The proteids in the various tissues serve the *double purpose* of forming a working constituent of the cell protoplasm and of supplying reserve food material. That the tissue proteid is used to liberate energy in the body and, in this way, serves as storage material is shown by the rapid loss of proteids in starving animals.

Other facts of interest relating to the storage of food are:

1. The form into which a food is converted for storage is of the nature of a solid which can be changed back to its former condition and re-enter the blood.

2. Only energy-yielding foods are stored. Water and salts, while they may be absorbed in excess of the needs of the body are not stored by conversion into other substances.

3. The interval of storage may be long or short corresponding to the needs of the body.

4. In the consumption of storage material the glycogen is used first, then, as a rule, the fat, and last of all the proteid.

Regulation of Food Supply to the Cells. The storage of foods not only enables the body to supply the needs of the cells during intervals when no food is taken, but also provides a means for regulating the rate of the supply of materials to the cells. The cells obtain their materials from the lymph and the lymph is supplied from the blood. When food substances, such as sugar, increase in the blood beyond a low per cent, they are converted into a form, like glycogen, in which they are held in reserve, or, for the time being, placed beyond the reach of the cells. When, however, the supply in the blood is being reduced, the stored material re-enters the blood and again becomes available to the cells. In this way the rate of supply may be practically constant.

We are now in a position to understand why carbohydrates, fats, and proteids are so well adapted to the needs of the body, while other substances like alcohol, which liberate energy, prove injurious.

Why Alcohol is not a Food. If the passage of alcohol through the body be followed it is seen, in the first place, that it undergoes no digestive change, and in the second place, that it is rapidly absorbed from the stomach in both weak and concentrated solutions. This introduces it quickly into the blood and, once there, it diffuses

rapidly into the lymph and then into the cells. Since it cannot be stored as alcohol or converted into some storage substance like fat,* or glycogen, there is no way of regulating the amount that shall be present in the blood, or of supplying it to the cells as their needs require. They must take it in whatever quantities it is introduced into the body, regardless of the effect. It is thus seen that, since alcohol is not adapted to the body's plan of taking up material and supplying it to the cells, it cannot be classed as a food.

Assimilation is the appropriation of food material by the cells. In a sense the storage of fat by connective tissue cells and of glycogen by the liver cells is assimilation. The term, however, is limited to the taking up of material that is to be used by the cell in serving its own purposes. Whether all of the materials used by the cells actually become a part of their protoplasm, is not known. It is known, however, that in the protoplasm of the cells is where the oxidations of the body occur and that materials taking part in these oxidations must, at least, come in close contact with the protoplasm. Assimilation is then the last event in a series of processes by which oxygen, food materials, and the cell protoplasm are brought into close and active relations with each other. Table I.

Enzymes. The chemical changes in digestion, absorption, storage, and assimilation, as well as the oxidations at the cells, are brought about, to a large extent, by the action of a class of substances, called ferments, or enzymes. These are found in the digestive fluids, as already noted, and also in the different tissues. They are likewise the cause of certain chemical changes that occur outside of the body, such as fermentation and decay. Some of the characteristics of enzymes are as follows:

1. They require a certain temperature for their action.
2. They are destroyed if the temperature is too high.
3. They are not used up in the process like the ordinary chemical reagents.
4. Their action is checked by an excess of the material which they form and, under certain conditions, is reversed.

From a chemical standpoint enzymes are classed with substances

* The fat that results from the excessive use of beer is due to the diminished oxidation of fats and carbohydrates and is in no sense a conversion of alcohol into fat.

that act by their presence to influence chemical reactions and are known as catalytic agents.

TABLE I. THE PASSAGE OF MATERIALS TO THE CELLS.

Materials.	Digestion.	Absorption.	Route to the general circulation.	Storage.	Condition in the blood.
Proteids.	Changed into proteoses and peptones by the action of the gastric and pancreatic juices.	In passing into the capillaries, the proteoses and peptones change into the albumins of the blood.	Through the portal vein to the liver and from there through the hepatic vein into the inferior vena cava.	Become a part of the protoplasm of all the cells.	As albumins in colloidal solution.
Fat.	Changed into fatty acid, glycerine and soluble soap by the bile and pancreatic juices.	In passing into the lacteals, the glycerine unites with the soluble soap and fatty acid to form the oil droplets of the blood.	Through the lacteals to the thoracic duct by which it is emptied into the left subclavian vein.	As fat in the cells of connective tissue.	Chiefly as minute drops of oil.
Starch.	Reduced to some of the different forms of sugar as maltose or glucose.	Enters the capillaries as a form of glucose, called dextrose.	Through portal vein, liver, hepatic vein into the inferior vena cava.	As glycogen chiefly by the liver but to some extent by muscle cells.	As a form of glucose in solution.
Water.	Undergoes no change.	Taken up both by the lacteals and capillaries but to the greater extent by the capillaries.	Takes both routes, but passes in larger quantities via the liver.	Is not stored in the sense that energy foods are.	As the water which serves as a carrier of all the other constituents of the blood.
Salts.	Undergo no change.	Taken up by the capillaries without undergoing a parent change.	Pass via the portal vein, liver, and hepatic vein into the inferior vena cava.	Not stored in the body.	In solution.
Oxygen.		Taken up by the capillaries at the lungs.			United with the haemoglobin and to a small extent in solution in the plasma.

Summary. Digested food material is taken up by the capillaries and the lymph vessels and transferred by two routes to the circulation. In passing through the epithelial lining of the canal the more important foods undergo changes that adapt them to conditions found in the blood stream. Since materials are not to be used as rapidly as they are taken up, provisions are made for storing them in the body and for supplying them to the cells as their needs require. In the production of the chemical changes incident to digestion, absorption, and storage of food, as well as the oxidation at the cells, the presence of active agents called enzymes is necessary.

Review Questions. 1. How does the absorption of food material differ from that of a liquid by a solid?

2. In what respects is the small intestine especially adapted to absorption?

3. What are the parts of a villus? What are the lacteals?

4. What part is played by the capillaries and lacteals in the work of absorption?

5. What changes, if any, take place in water, salts, fats, and carbohydrates during absorption?

6. What double purpose is served by the epithelial layer?

7. Trace the passage of proteids, fats, and carbohydrates from the small intestine to the general circulation.

8. What is the necessity for storing up foods in the body? Why is it not also necessary to store up oxygen?

9. In what form is each of the principal classes of foods stored?

10. How is the rate of supply of food to the cells regulated? Why is the body unable to regulate the supply of alcohol to the cells when this substance is taken?

11. How does assimilation differ from storage of food materials?

12. What role is played by the enzymes in the body? What enzymes are found in each of the digestive fluids?

CHAPTER XI.

LIBERATION OF ENERGY IN THE BODY.

Energy. The human body, in common with all the higher animal forms, is characterized by movements, bodily warmth, and complex internal processes. All these activities are brought about through the *expenditure of energy*. Energy is power. It may be stored up in a body, or it may be in the condition of being expended. In the former state it is known as *potential*, or latent energy; in the latter as *kinetic*, or active, energy. The reserve energy of the body is potential. It becomes kinetic as it is being used in various ways.

Nature of Potential Energy. Much of the potential energy about us is due to the manifest tendency of substances to collect into larger masses and to form various combinations. While this tendency is not understood, it may be conveniently thought of as a kind of attraction, and different forms of it, as gravitation, cohesion, etc., are recognized. If two bodies having an attraction for each other are separated they tend to move toward each other. Since they have the capability of motion they possess energy. The storing of energy in such bodies is simply a matter of *separating* them. Thus if a stone is raised above the earth gravitation may cause it to return, or if rubber is stretched cohesion may cause it to shorten again. In all such cases the energy expended in producing the separation becomes potential and so remains as long as the separation exists.

Chemical Potential Energy. While there are different forms of potential energy as suggested above, that known as chemical potential energy is of chief importance in its relation to the body. This form is made possible by the existence of a force called chemical affinity or chemism. Chemism is the attraction between atoms, the smallest particles found in matter. A body possesses chemical potential energy when its atoms are separated from the atoms of other bodies for which they have attraction. Gunpowder is a good example of a substance having chemical potential energy. It is pre-

pared by mixing (not uniting) in correct proportions, sulphur, carbon, and a compound called potassium nitrate, which is rich in oxygen. The atoms of the sulphur and carbon have a strong attraction for the atoms of oxygen. When the temperature of the powder is raised sufficiently the atoms move toward each other and unite to form new compounds. In this way their potential energy, becomes kinetic, causing the explosion.

Nature's Storehouse of Energy. In a somewhat similar manner, the earth's greatest supply of potential energy is made possible. In the atmosphere is found a large amount of free oxygen. On the earth are many substances which contain elements, the atoms of which have a strong affinity for the atoms of oxygen. By complying with certain known conditions a union between these elements and oxygen is brought about. Combustion is the result of such a union. It thus happens that the oxygen of the air on the one hand and the products of plant life—wood, coal, etc.—on the other hand, because of the mutual attraction of their atoms, and their condition of separation, provide a great supply of chemical potential energy.

For the keeping up of this supply we are dependent upon vegetation. In the separation of carbon dioxide into carbon and oxygen (p. 43), the plant places these elements in such a condition that they are again able to unite. The sunlight, which works through the plant, is the real cause of the separation and the energy of the separated oxygen and carbon is in a sense the stored up energy of the sun.

Forms of Kinetic Energy. In the burning of wood the chemical potential energy of the oxygen of the air and the carbon of the wood is transformed into kinetic energy. This appears in the form of heat and also of light. If the heat is applied to water, steam is produced, which may cause the motion of machinery, and this by turning a dynamo causes electrical energy. These activities suggest the more important forms of kinetic energy, which are heat, light, mechanical motion, and electrical energy. These are related, in the sense that all are forms of motion, and each is convertible into the other.

The Energy of the Body. To supply the energy needed by the body is one of the most difficult problems of animal life. The animal cannot create energy; neither can it, like the plant, use the kinetic energy which may come to it from the sun. Its only resource is to obtain it in the potential form. To do this it must draw from the storehouse of nature and utilize the energy there contained in the oxygen of the air and the products of vegetation. This is ac-

complished by passing the oxygen and food to the cells where the conditions are favorable for their union. Until their union occurs the energy remains potential, but in the act of uniting it becomes kinetic and may be used in the work of the body.

A fact of importance in the liberation of energy is that the rate is just sufficient to supply the needs of the body. It is easily seen that too rapid or too slow a rate would prove injurious. The oxidations at the cells are therefore under control and the quantity of energy supplied to the body as a whole and to the different organs is proportional to the work that is done.

Animal Heat and Motion. Most of the body's energy is expended as heat and motion. Of the whole amount it is estimated that as much as five-sixths is used as heat. The proportion, however, varies with different persons and is not constant in the same individual, during different seasons of the year. The heat is used in keeping the body at that temperature which is best suited to carrying on the vital processes. This is 98.5° F. and is called the *normal temperature*. To maintain this temperature uniformly through all the varying conditions within, and on the outside of the body, requires a very delicate adjustment of the heat-producing and regulating processes. All parts of the body, through oxidation, furnish heat. Active organs, however, such as muscles, the brain, and glands furnish a larger share. The blood in its passage through the body serves as a *heat distributor* and keeps the temperature about the same in all parts. The production of motion is considered in the study of the muscular system.

Hygiene. *The heat producing capacity* of the body sustains a very important relation to the general health. A sudden chill may result in a number of derangements and is the usual cause of *colds*. One's capacity for producing heat may be so low that he is unable to respond to a sudden demand for heat, as in going from a warm into a cold room. As a consequence, the body is unable to protect itself against unavoidable exposures.

Impairment of the heat-producing capacity is brought about in many ways. Several diseases do this directly, or indirectly, to quite an extent. In health excessive care in protecting the body from cold is perhaps the most potent cause of its impairment. Staying in rooms heated above a temperature of 70° F., wearing clothing unnecessarily heavy, and sleeping under an excess of bed clothes,

diminish the power to produce heat, by accustoming the body to producing only a small amount. Lack of physical exercise in the open air, as well as too much time spent in poorly lighted and ventilated rooms, tend also to diminish it. Since most of the heat of the body comes by the union of oxygen with the food materials in the cells, a lack of either will interfere with the production of heat.

Exhaustion. The energy at the disposal of the body is spent in two general ways: First, in carrying on the vital processes and second, in the performance of voluntary activities. Since, in all cases, there is a limit to one's energy, it is easily possible to expend so much in the pursuit of one's business, or in pleasurable exercise, that the amount left is not sufficient for the proper maintenance of the vital processes. This is the condition when one has overworked or has exercised beyond his strength. A lack of energy for the vital processes leads to disturbances that render the body less able to obtain a requisite supply and in time leads to serious results. The remedy in such cases lies in the removal of the cause, and not in the use of stimulants.

Simple Experiments. 1. The change of *kinetic into potential energy* may be shown by stretching a piece of rubber, lifting a body, separating the armature from a magnet, and by decomposing water with an electrical current.

2. The change of *potential energy into kinetic* may be shown by letting bodies fall, releasing the end of a stretched piece of rubber, and by the burning of wood.

3. The change of one form of kinetic energy into another form may be illustrated by rubbing together two pieces of wood until they become heated, by ringing a bell, and by causing motion in air and water by heating them. If suitable apparatus is at hand, the transformation of electrical energy into heat, light, sound, or mechanical motion can easily be shown.

Summary. The body requires a continuous supply of energy. To obtain this, materials possessing chemical potential energy are introduced. Oxygen and food substances, because of their ability to unite chemically in the body, can be utilized for this purpose. So long as the foods are not oxidized the energy remains in the potential form in the body. In the process of oxidation the potential is changed into kinetic energy and is expended in the form of heat and motion, and in other ways.

Review Questions. 1. What are the proofs that the body possesses energy?

2. Show that a stone lying against the earth has no energy, while the same stone above the earth has energy.

3. Water is composed of hydrogen and oxygen, which have an attraction for each other. Why then does not water contain potential energy?

4. What kind of energy is possessed by a bent bow, a revolving wheel, a coiled spring, the wind?

5. Why is it necessary to separate bodies having an attraction for each other, in order to give them energy?

6. Account for the energy possessed by the oxygen of the air and food substances.

7. How does the body obtain its supply of energy?

8. In what different ways does the body expend its energy?

9. How may over-work or over-exercise injure the body?

CHAPTER XII.

THE EXCRETORY WORK OF GLANDS.

Glands are organs that prepare special liquids in the body and pour them out upon free surfaces. These liquids, called *secretions*, are separable into two classes, known as the *useful* and the *useless* secretions. To the first class belong all secretions that are made to serve some purpose in the body, while the second includes the liquids separated as waste products from the blood. The first are usually designated as true secretions, or secretions proper, and the second as *excretions*. The most important glands producing liquids belonging to the first class are those of digestion. (Chapter IX.)

General Structure of Glands. While the various glands differ widely in size, form, and purpose, they present striking similarities in structure. The active agents in all the glands are the so-called gland, or *secreting*, cells. These are usually cubical in form and are always spread over a connective tissue support, known as the *basement membrane*. Beneath the gland cells and penetrating the basement membrane are numerous capillaries and lymph vessels, as well as nerve fibers. These structures—gland cells, basement membrane, capillaries, lymph vessels, and nerve fibers—form the essential parts of all glands. The capillaries and lymph vessels supply the gland cells with blood, the nerves control the time and rate of secretion, while the basement membrane forms a suitable support for all these parts.

Kinds of Glands. Glands differ from each other chiefly in the arrangement of their essential parts. The simplest disposition of these parts is that of spreading them over a smooth surface as in the pleura and the pericardium. Such an arrangement is not usually known as a gland, but is called a *secreting surface*. It produces but a small amount of liquid for the surface employed and is not adapted to conditions requiring large amounts of liquid. A somewhat more complex arrangement is that where the gland elements are made to

line the interiors of small cavities which are formed by the folding, or pitting, of exposed surfaces. Such glands are found chiefly in the mucous membrane, especially that lining the alimentary canal. In the stomach they are quite numerous, supplying the gastric juice. If these glands have the general form of tubes they are called *tubular* glands; if sac-like in shape they are called *sacular*, or *racemose*, glands. Both the tubular and the sacular glands may, by branching, form a great number of similar divisions which are connected with

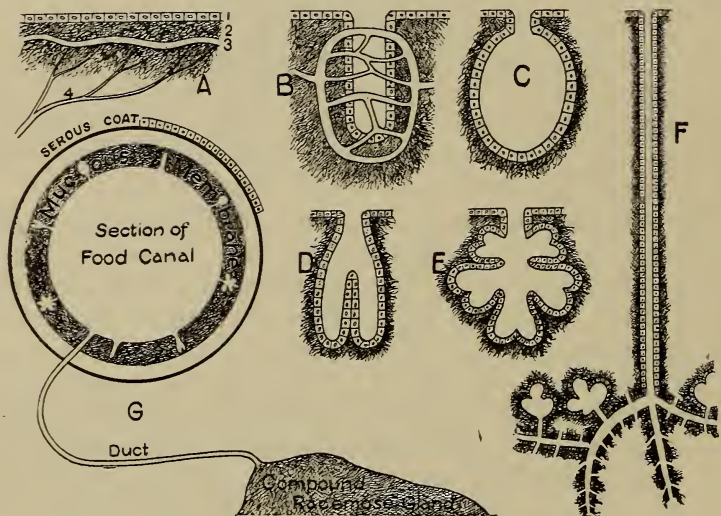


Fig. 20. Evolution of glands. A. Simple secreting surface. 1. Gland cells. 2. Basement membrane. 3. Blood vessel. 4. Nerve. B. Simple tubular gland. C. Simple sacular gland. D. Compound tubular gland. E. Compound sacular gland. F. A compound racemose gland with duct passing to a free surface. G. Relation of food canal to different forms of glands.

each other and which communicate, by a common duct, with the place where the secretion is used. This forms the *compound* gland which, depending upon the structure of the minute parts, may be either a compound tubular or a compound racemose gland. The gastric and the perspiratory glands are good examples of tubular glands, while the oil glands of the skin are sacular glands. The large glands, such as the pancreas and the salivary, belong to the compound racemose type, while the kidneys are compound tubular glands. Fig. 20.

Nature of the Secretory Process. The secretions are found to contain materials, such as water and salts, that are found in the blood. They also contain materials that are not found in the blood but have been supplied by the glands. Important changes within the gland cells are also known to take place during the time of secretion. If, for example, the cells of the pancreas be examined microscopically after a period of rest, they will be found to contain many small granular bodies. On the other hand, if they be examined after a period of activity, the granules have disappeared and the cells themselves have become smaller in size. These granules have, no doubt, been used in forming the secretion. These facts have led to the conclusion that secretion is, in part, a separation of materials from the blood and, in part, a process by which specific substances are manufactured and added to the secretions.

Excretion, the process of removing waste materials from the body, is made necessary by the results attending oxidation at the cells. (P. 40.) The final products of oxidation are of such a nature that they can no longer take any part in the vital processes. They correspond to the ashes and gases that are produced in ordinary combustion and form so much waste that must be removed. The most important of such products are the following:

1. *Carbon dioxide* (CO_2) which is formed by the union of oxygen with the carbon of the food substances and the protoplasm. In its natural condition it is a gas, but in the body it is dissolved in different liquids and is in chemical combination.

2. *Water* (H_2O) which is formed in the body, to some extent, by the union of oxygen with the hydrogen of food substances and to that degree is a waste product. This, however, is but a small fraction of the total amount that passes through the body. It is, of course, a liquid and as such enters and leaves the body.

3. *Urea** ($\text{CO}(\text{NH}_2)_2$) which is formed by the union of oxygen with nitrogenous compounds. It is a solid substance, but is soluble in water and while in the body is in solution.

4. *Salts*. These comprise a number of different materials

* In the oxidations that occur in the body it is not supposed that the food substances are immediately oxidized to carbon dioxide, water, and urea. On the other hand, it is held that the reduction takes place gradually, as in the reduction of sugar by fermentation, and that these waste products show only the final results.

some of which are formed in the body, while others, like common salt, enter as a part of the food. They are solids, but leave the body dissolved in water.

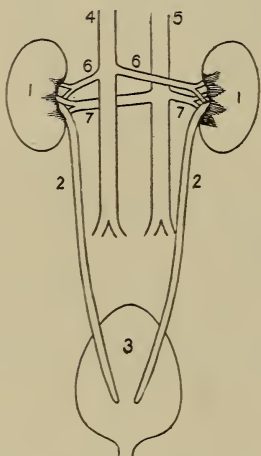
These substances, if left in the body, interfere with its work and in a short time cause death. Their removal, which is as necessary as the introduction of food materials and oxygen into the body, is largely the work of glands.

General Plan of Excretion. From the cells, where they are formed, the waste materials pass into the lymph and from the lymph find their way into the blood. As a part of the blood they are circulated over the body and at certain places enter the organs, by which they are separated. They are then passed to the exterior of the body. The glands that serve as excretory organs are the kidneys, liver, and perspiratory glands.

The Kidneys. The kidneys are two bean-shaped glands situated in the back and upper portion of the abdominal cavity, one on each side of the spinal column. They weigh from four to six ounces each, and lie between the abdominal wall and the peritoneum. Two large arteries from the aorta, called the *renal arteries*, supply them with blood, while they are connected with the inferior vena cava by the *renal veins*. They remove from the blood an exceedingly complex liquid called the *urine*, the principal constituents of which are water, salts of different kinds, and urea. The kidneys pass their secretion by two slender tubes, the *ureters*, to a reservoir called the bladder. Fig. 21.

Fig. 21. Relations of the kidneys. (Back view.) 1. The kidneys. 2. Ureters. 3. Bladder. 4. Aorta. 5. Inferior vena cava. 6. Renal arteries. 7. Renal vein.

Minute Structure of the Kidneys. Each kidney is a compound tubular gland and is composed chiefly of the parts concerned in its work. These consist of many small blood vessels and a system of minute tubes called the *uriniferous tubes*. Each uriniferous tube starts at the outer margin of the kid-



ney in a globular enlargement, called the Malpighian capsule, which incloses a cluster of capillaries. Fig. 22. From here the tube extends toward the concave side of the kidney, where it terminates. Between its origin and termination, however, are several convolutions and one or more loops or turns.

Fig. 22. Enlarged Malpighian capsule and uriniferous tube. 1, 2, Blood vessels. 3, Epithelial lining of capsule. 4, Lining of the uriniferous tube.

Finally, after passing a distance much greater than from the margin to the center of the kidney and after joining with other similar tubes, it empties its contents into one of the branches of the ureter. The uriniferous tube is lined throughout its entire length by *secreting cells*, which, differing slightly at different places, rest upon a basement membrane well supplied with capillaries. These cells are the active agents in separating impurities from the blood.

Blood Supply. The renal artery enters the kidney by four branches which, by dividing, send smaller divisions to all parts. At the margin of the kidney, called the cortex, the blood is passed through two systems of capillaries. The first form clusters within the Malpighian capsules and receive the blood direct from the smallest arteries. The second form a network around the uriniferous tubes and receive the blood which has passed from the capillary clusters into a system of small veins. From the last system of capillaries the blood is collected into veins that pass from the kidneys where the artery branches enter and, by uniting, form the renal veins. Fig. 23. In the central part of the kidney the blood passes through but a single system of capillaries.

The Work of the Kidneys is done in part at the capsules and in part along the whole length of the uriniferous tubes. Water and salts are removed chiefly at the capsules while the remaining

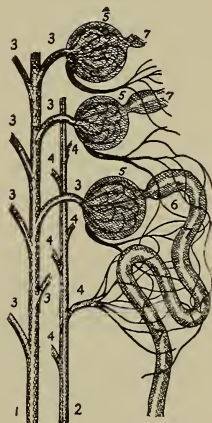


Fig. 23. Diagram of the circulation in the kidneys. 1. Small branch of renal artery. 2. Small branch of renal vein. 3. Arterial branches entering capsules. 4. Branches of veins. 5. Malpighian capsules. 6. Capillaries around the uriniferous tubes. 7. Uriniferous tubes.

solids are removed by the cells that line the tubes.

The kidneys are the only organs of the body that are purely excretory in function. All the others that remove waste have additional functions. This fact, together with the service which the kidneys actually render, cause them to be classed as the most important of the excretory organs.

Urea is the most abundant solid constituent of the urine and is the chief waste product arising from the oxidation of nitrogenous substances. It is not formed, however, by the kidneys nor at the muscles where the proteids are broken down in largest quantity. Its formation in the body has been found to be the work of the liver and to take place as follows: In the tissues the proteids are reduced to a lower order of nitrogenous compounds, such as compounds of ammonia, which are then taken to the liver where, by the action of the liver cells, they are converted into urea. The urea then passes into the blood, from which it is separated by the kidneys.

The Liver as an Excretory Gland. The liver assists in the work of excretion in two ways, as follows: 1. By changing waste nitrogenous substances into urea, as already stated. 2. By removing from the blood the waste products that appear in the bile.

Along with other waste, the bile contains the products of decomposition from the haemoglobin of the red corpuscles. These give the bile its characteristic color and are known as bile pigments. The bile also contains a substance resembling fat, called cholesterin, which is supposed to be a waste product from nervous tissue. Salts of different kinds also appear in the bile.

Functions of the Liver. While the chief work of the liver is not that of excretion, its functions may here be summarized. The liver is, first of all, a manufacturing organ, producing as we have seen three distinct products—bile, glycogen, and urea. The nature of these substances and their treatment in the body cause the liver to be classed as an organ of digestion, a storage organ, and an organ of excretion. These functions make of the liver an organ of the first importance.

The Perspiratory or Sweat Glands are located in the skin. They belong to the type of simple tubular glands and are very numerous over the entire surface of the body.

The sweat glands secrete a colorless, watery fluid called perspir-

ation, or sweat, which contains, besides water, a small per cent of salts and urea. While the excretory work of these glands seems not so great as was formerly supposed, they supplement in a practical way the work of the kidneys and, during diseases of these organs, increase their excretory work to a marked degree. The perspiration also plays an important role in the regulation of the temperature of the body. (Chapter XV.)

The Glands of the Food Canal, while secreting liquids that are used in digestion, also separate materials from the blood that may be regarded as waste. These are passed from the canal along with the waste from the liver and the undigested particles of food.

Excretory Work of the Lungs. While the lungs cannot be regarded as glands, they do a work in removing waste from the body which must be considered in the general process of excretion. As already noted (p. 30) they are especially adapted to removing gaseous substances from the blood and it is through them that most of the carbon dioxide leaves the body. A considerable quantity of water is removed in the form of vapor, as may be shown by breathing against a cold window pane.

TABLE II. THE PASSAGE OF WASTE MATERIALS FROM THE CELLS.

Materials.	State to which they belong.	How formed in the body.	Condition in the blood.	How removed from the blood.
Carbon dioxide.	Gaseous.	By the oxidation of the carbon of proteids, carbohydrates, and fats.	Dissolved in the plasma and in loose combination with salts in the blood.	Separated from the blood at the alveoli of the lungs and then forced through the air passages to the outside atmosphere.
Urea.	Solid.	By the oxidation at the tissues and in the liver of nitrogenous compounds.	Dissolved in the plasma.	Removed by the uriniferous tubes of the kidneys and, to a small extent, by the perspiratory tubes.
Water.	Liquid.	By the oxidation of the hydrogen of proteids, carbohydrates, and fats. Amount formed in the body is small.	As water.	Removed by all the organs of excretion, but in the largest quantities by the kidneys and skin.
Salts.	Solid.		In solution.	By the kidneys and skin.

Quantity of Excretory Products. If the weight of the normal body be taken at intervals, after growth has been attained, there will be found to be practically no gain or loss from time to time. This shows that materials are leaving the body as fast as they enter* and that the tissues are being torn down as rapidly as they are built up. It also shows that substances do not remain in the body *permanently* but only so long, perhaps, as is necessary for them to give up their energy, or to serve some additional purpose in the everchanging protoplasm. The excretory organs then remove from the body a quantity of material that is practically equal in weight to the material absorbed at the organs of digestion and respiration. This is estimated for the average individual to be about five pounds daily.

Ductless Glands. Midway in function between the glands that secrete useful liquids and those that remove waste materials from the blood, is a class of bodies found at various places known as the *ductless glands*. They are so named from their general form, which is similar to that of glands, and not from their structure, which is usually different. As their name implies, they possess no external openings or ducts. They are in communication, however, with the circulation and are supposed to act upon the blood, either by removing substances from it or by manufacturing and adding substances to it. The most important of the ductless glands are the spleen, the thyroid gland, the suprarenal bodies, and the thymus gland.

Health Suggestions. Physical exercise, by increasing the circulation, facilitates the work of excretion, especially that done by the skin. The work devolving upon the kidneys may be lessened by keeping the skin clean and active. The kidneys may also be saved extra and useless work by avoiding an excess of proteid foods, such as meats. To a certain point proteids are needed as tissue builders, but if taken beyond this they are reduced by the liver to glycogen and urea before reaching the tissues. For this reason an excess of proteids may overwork both the liver and the kidneys. A condition of inactivity of the bowels should, if possible, be avoided as this leads to reabsorption of waste in the food canal. As a rule the work of excretion is also facilitated by drinking freely of pure water. This

* As a matter of fact, a small per cent of the material does find permanent lodgment, chiefly in the bones and connective tissue, and to some extent in all the tissues. Its presence is indicated by the changes that the tissues undergo with age.

liquid, acting as the natural solvent and transporter of waste material, has these essential qualities increased, by an increase, within certain limits, of the amount taken into the body.

Summary. As a result of the oxidations at the cells, substances are produced which can no longer serve a purpose in the body. They are of the nature of waste and their continuous removal is as necessary to the maintenance of life as the introduction of food and oxygen. The organs whose work is to remove the waste, excepting the lungs, are glands; and the materials which they remove are of the nature of useless secretions. From the cells, the waste passes through the lymph into the blood. From the blood it is separated by the excretory organs and passed to the exterior of the body.

Review Questions. 1. What general purposes are served by the glands in the body?

2. What are the parts common to all glands? What purpose is served by each of these parts?

3. Trace the evolution of glands from the simple secreting surface. How do tubular differ from sacular glands?

4. Describe the nature of the secretory process.

5. What conditions render necessary the formation of waste substances in the body? Why must they be removed?

6. How do impurities get from the cells to the organs of excretion?

7. In what do the uriniferous tubes have their beginning? In what do they terminate? With what are they lined?

8. Bright's disease of the kidneys affects the uriniferous tubes and interferes with their work. What impurity is then left in the blood?

9. Trace water and salts from where they are removed from the blood through the different tubes to the bladder.

10. Trace carbon dioxide from the cells to the outside atmosphere.

SUMMARY OF PART I.

Our study so far has shown that the body is an aggregation of different kinds of cells; that it grows by the growth and reproduction of these cells; and that its life as a whole is maintained by keeping them alive. For ministering to the wants of the cells two liquids (the lymph and the blood) are employed. To keep the blood and lymph in the proper condition for ministering to the cells the organs of circulation, respiration, digestion, secretion, and excretion are employed. Through the combined action of these organs two general movements of materials are kept up in the body, as follows:

1. An *inward* movement which carries material from the outside of the body toward the cells.
2. An *outward* movement which carries material from the cells to the outside of the body.

Passing *inward* are the oxygen and food materials in a condition to unite with each other and thereby change their potential into kinetic energy. Passing *outward* are the oxygen and the elements that formed the food material *after* they have united at the cells and liberated their energy. (Fig. 1.)

As a final and all important result there is kept up a *continuous series of chemical changes* in the cells. These liberate energy, provide material for the growth and repair of the tissues, and preserve the life of the body.

PART II.

MOTION, CO-ORDINATION, SENSATION.

CHAPTER XIII.

THE SKELETON.

The Tissues Employed in the construction of the skeleton, or framework of the body, are the osseous, cartilaginous, and connective and are known as the supporting tissues. They form the bones, supply the elastic pads at their ends and furnish strong bands, or ligaments, for fastening them together. The tissues of the skeleton possess properties that adapt them to their purposes. The separate units or parts from which the skeleton is constructed are the bones. These, as usually estimated, are 208 in number and vary greatly in size and shape.

The Properties and Composition of Bone are indicated to some extent by the following

Experiments: 1. Examine a slender bone, like that in the leg of a chicken. Note that it resists bending and is difficult to break. Note also that when slightly bent it will spring back.

2. Soak such a bone over night in a mixture of one part of hydrochloric acid and four parts of water. Then ascertain by bending, stretching and twisting what properties, if any, the bone has lost.

3. Burn a small piece of bone in a clear gas flame, or on a bed of coals, until it ceases to blaze and becomes white in color. Can the bone now be bent or twisted? What properties has it lost, and what retained, by the burning?

The acid dissolves the material which gives the bone its property of stiffness. This is called the *mineral matter* and consists chiefly of phosphate and carbonate of calcium.

Burning, on the other hand, destroys the material which gives the bone its toughness and elasticity. This is called the *animal matter*. This consists mainly of a substance, called ossein, which can be removed from the bones by boiling and is then known as gelatine. The blood vessels and nerves in the bone and the protoplasm of the bone cells are also counted in with the animal matter.

If a bone from a full grown, but not old animal be weighed before and after being burned, it will be found to have lost about one-third of its weight. From this we may conclude that one-third of the bone by weight is animal matter and two-thirds is mineral. This proportion, however, varies with age, the mineral matter increasing with advance of years.

The Gross Structure of Bone is best learned by studying both dry and fresh specimens, as follows:

Observations. 1. Procure a long, dry bone. One that has lain out in a field until it has bleached will answer the purpose excellently. Test its hardness, strength, and stiffness. Saw it in two, a third of the distance from one end and saw the shorter piece in two, lengthwise. Compare the structure at different places. Find rough elevations on the outside for the attachment of muscles, and small openings into the bone for the entrance of blood vessels and nerves. Make drawings to represent the sections.

2. Procure a fresh bone from a butcher shop. Note the difference between it and the dry bone. Examine the materials surrounding the sides and covering the ends. Saw through the enlarged portion at the end and examine the red marrow. Saw through the middle of the bone and observe the yellow marrow.



Fig. 24. Section of a long bone. 1. Marrow cavity. 2. Compact tissue. 3. Cellular tissue. 4. Cartilage. 5. Attached ligaments and tendons. 6. Periosteum.

The ends of the bones are capped by a layer of cartilage which is elastic, while the remaining surface is covered by a dense sheath of connective tissue, called the *periosteum*. Usually the central part is hollow, being filled with a fatty substance, known as the *yellow marrow*. Around the marrow cavity the bone is very dense and compact. The red marrow, whose relation to the red corpuscles has already been noted (p. 10), is found in the spongy tissue at the ends.

The Minute Structure of the bone can be studied only by the aid of a compound microscope.

Observation. Prepare a section of bone for microscopic study, as follows: With a jeweler's saw cut as thin a section of bone as possible. Place this between two good-sized whetstones (having not too much grit), cover with water, and rub until thin enough to allow the light to pass through. The section may then be wet with water and examined under a cover glass, or it may be mounted in hard balsam and kept indefinitely. Such sections are most satisfactory when prepared from bones that are thoroughly dry, but which have not begun to decay. Prepare and study both transverse and longitudinal sections, making drawings.

Such a microscopic study shows two kinds of small canals which penetrate all portions of the bone. These are known as the *Haversian canals* and the *canaliculi*. The Haversian canals are larger than the canaliculi, extend the long way of the bone, and each is surrounded by several thin layers, or *liminae*, of bone substance. The canaliculi extend from the Haversian canals at right angles toward a great number of irregular clusters in the bone layers, called the *lacunae*. These, together with the canaliculi, present an appearance under the microscope similar to that of a number of large burs fastened together by their projecting spines. The walls of the lacunae are hard and dense, but within each is an open space. In this lies a flattened nucleated body that sends branches into the canaliculi. This is the bone cell, or *bone corpuscle*, as it is sometimes called. The chief work of the bone cell seems to be that of depositing mineral matter in the walls surrounding it.

How the Bone Cells are Nourished. The bone cells, like all the other cells of the body, are nourished by the lymph that escapes from the blood. This reaches the cells in the different parts of the bone in two ways, as follows:

1. The cells at the *surface* of the bone receive lymph from the blood vessels in the periosteum. It comes to them through the canaliculi passing from the outside of the bone to the lacunae near its surface.

2. The cells *within* the bone receive nourishment through the channels penetrating it. Many of these are large enough to be seen with the naked eye and inclose small veins and arteries; others, such as the Haversian canals, contain capillaries. The canaliculi convey lymph from the capillaries to the bone cells.

The Plan and Purpose of the Skeleton. The plan of the skeleton is such as to provide a framework for a *movable* structure. Obviously the different parts of the body cannot be secured to a foundation, as are those of a stationary building, but must be

arranged after a plan that is conducive to motion. A moving structure, as a wagon or a bicycle, has within it some strong central part to which the remainder is joined. The same is true of the skeleton. The part to which the others are joined consists of a long bony axis, called the *spinal column*. The skull, the ribs, and the pelvic bones are attached directly to the spinal column, while the other parts are attached indirectly. The arrangement of all the parts is such that the spinal column is made the central, cohering portion of the skeleton and also of the whole body.

Bone Groups. Very few bones of the body can be regarded as possessing distinct value in themselves. Each bone, however, is a part of some group and contributes to the purpose which that group serves. The individual bones must not, therefore, be studied singly but with reference to the groups to which they belong. The more important groups are as follows:

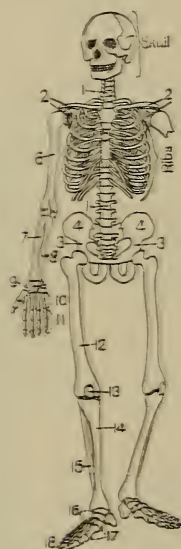


Fig. 25. The skeleton. 1. Spinal column. 2. Shoulder girdle. 3. Pelvic girdle. 4. Hip bones. 5. Sternum. 6. Humerus. 7. Radius. 8. Ulna. 9. Carpus. 10. Metacarpus. 11. Phalanges of fingers. 12. Femur. 13. Knee cap or patella. 14. Tibia. 15. Fibula. 16. Tarsus. 17. Metatarsus. 18. Phalanges of toes.

The *spinal column*, which consists of twenty-four similarly shaped bones, one placed above the other, called vertebrae,* in addition to two groups of fused vertebrae found at the lower end. This group supplies the central axis for the body, supports the head and upper extremities, and incloses and protects the spinal cord. The upper seven vertebrae form the neck and are called the *cervical* vertebrae. They are smaller and have greater freedom of motion than the others. The two upper cervicals are specially modified to support the head and to provide for its movements. The next twelve vertebrae, in order below the cervical, are the *thoracic*. They form the back part of the framework of the thorax and have little freedom of

*A typical vertebra consists of a heavy disk-shaped portion in front, called

motion. The five below the thoracic are known as the *lumbar* vertebrae. They are large and strong but admit of considerable motion. At the lower end of the column five vertebrae are fused together, forming a wedge-shaped bone, called the *sacrum*. To the sacrum is attached a group of from two to four small vertebrae, more or less fused, called the *coccyx*.

2. *The skull*, which is formed by the close union of twenty-two irregular bones. For purposes of study, the skull is divided into the cranium and the face. The cranium consists of eight distinct bones, and incloses the cranial cavity which holds the brain. The face group, consisting of fourteen bones, provides supports for the parts of the face and supplies a movable part (the inferior maxillary) which aids in mastication.

3. *The thorax*, which contains twenty-four bones of similar form, called ribs, and a straight, flat bone, called the sternum, or breast-bone. The framework of the thorax is formed by the union of the ribs with the spinal column behind and the sternum in front. As already stated (p. 33), the ribs are so arranged that the volume of the thorax is varied by their elevation and depression, enabling the air to be drawn into and forced from the lungs.

4. *The shoulder and pelvic girdles*, which form two bony supports at the upper and lower portions of the trunk and serve for the attachment of the arms and legs. The shoulder girdle is formed by four bones—the two clavicles, or collar-bones and the two scapulae, or shoulder-blades. The clavicle on each side articulates with the upper end of the sternum and serves as a brace for the shoulder, while the

the body, which is connected by two lateral extensions with a posterior portion called the *neural* arch. The body and the neural arch together completely encircle a round opening which is a part of the canal that contains the spinal cord. From the neural arch are seven bony projections, or processes, three of which serve for the attachment of muscles and ligaments, while the other four, two superior and two inferior, are for interlocking the vertebrae with each other.

The different vertebrae are joined together in the column as follows: Between the bodies of the several vertebrae are disks of elastic cartilage, each of which is about one-fourth of an inch in thickness and is attached firmly to the vertebrae above and to the one below. In addition to these, the projections from the lower portion of the neural arch of each vertebra fit into the indentations of the neural arch over which it is placed and the two are firmly bound together by ligaments. To further secure one bone upon the other, numerous ligaments pass from vertebra to vertebra, on all sides of the column.

scapula forms a socket for the humerus and furnishes many places for the attachment of muscles.

The pelvic girdle is formed by two large bones which are very irregular in shape and are called the innominate bones. They connect behind with the lower part of the spinal column, called the sacrum, and in front they connect, through a small pad of cartilage, with each other. On the inside they present a smooth basin-shaped support for the contents of the abdomen, but on the outside are rough and uneven and provide many prominences for the attachment of muscles and ligaments. Each innominate bone provides a deep, round socket into which the femur of the leg accurately fits.

5. *The arm and hand groups.* A long bone, the humerus, connects the arm with the shoulder and gives form to the upper arm. In the forearm are two bones, the radius and the ulna, which connect at one end with the humerus and at the other, with the bones of the wrist.

A group of eight small rounded bones are found in the wrist. These, known as the carpal or wrist bones, are arranged in two rows which are movable upon each other. Five straight bones, the metacarpals, connect with the bones of the wrist and form the frame-work of the hand. The bones of the fingers and thumb connected with the metacarpals, are called phalanges.

The great number of bones found in the fingers, hand, wrist and forearm and the manner in which they are joined, permit great freedom of motion and enable the hand to be used in a variety of ways.

6. *The leg and foot groups.* These correspond in form and arrangement to the bones of the arm and hand. Since, however, the leg and foot form special organs of locomotion, certain differences are to be expected. The patella at the knee has no corresponding bone in the arm; and the carpus, or ankle, which corresponds to the wrist, contains seven instead of eight bones. The bones of the feet and toes are the same in number as those of the hand and fingers, but they differ greatly in form and size and have less freedom of motion. The femur which gives form to the thigh is the longest bone of the body. The tibia, or the shin bone, and the fibula, a slender bone, give form to the lower part of the leg.

Note.—To obtain clear ideas of the form and function of the bones, careful examination of a prepared and articulated skeleton is necessary. Many of the bones, however, may be located and their

general form made out from the living body. For descriptions of bones consult some work on anatomy. The different groups of bones are shown in figure 25 and named in Table III.

TABLE III. THE PRINCIPAL BONES AND THEIR GROUPING IN THE BODY.

I. AXIAL SKELETON.

A. Skull, 28.	B. Spinal Column, 26.
1. Cranium, 8. a. Frontal, forehead..... 1 b. Parietal..... 2 c. Temporals, temples..... 2 d. Occipital..... 1 e. Sphenoid..... 1 f. Ethmoid..... 1	1. Cervical, or neck vertebrae. 7 2. Dorsal, or thoracic vertebrae 12 3. Lumbar vertebrae..... 5 4. Sacrum..... 1 5. Coccyx..... 1
2. Face, 14. a. Inferior Maxillary..... 1 b. Superior Maxillaries..... 2 c. Palatine, palate..... 2 d. Nasal bones..... 2 e. Vomer..... 1 f. Inferior Turbinated..... 2 g. Lachrymals..... 2 h. Malars, cheek bones..... 2	C. Thorax, 25. 1. Ribs..... 24 2. Sternum..... 1
3. Bones of the Ear, 6. a. Malleus..... 2 b. Incus..... 2 c. Stapes..... 2	D. Hyoid, 1..... 1 Note—The hyoid, since it forms an arch similar to the lower jaw, is more properly classed as a bone of the skull.

II. APPENDICULAR SKELETON.

A. Shoulder Girdle, 4.	C. Pelvic Girdle, 2.
1. Clavicle, collar bone..... 2 2. Scapula, shoulder blade..... 2	1. Os innominatum..... 2
B. Upper Extremities, 60.	D. Lower Extremities, 60.
1. Humerus..... 2 2. Radius..... 2 3. Ulna..... 2 4. Carpals, wrist bones..... 16 5. Metacarpals..... 10 6. Phalanges, of the fingers..... 28	1. Femur, thigh bone..... 2 2. Tibia..... 2 3. Fibula..... 2 4. Patella, knee cap..... 2 5. Tarsals, ankle bones..... 14 6. Metatarsals, bones of the instep..... 10 7. Phalanges, of the toes..... 28

Adaptation to Special Needs. When any single bone is studied in its relation to the other members of the group to which it belongs or with particular reference to its purpose in the body, its adaptation to some particular place or use is at once apparent. It is seen that some bones like the humerus, are adapted to giving form, strength, and stiffness to certain parts, while others, like the pelvic

bones, are fitted for supporting and protecting organs. Others, as the wrist and ear bones, are suited to giving a peculiar kind of motion, and still others, such as the ribs, are adapted to a variety of purposes. The differences that appear among the bones, such as size, structure, form, and surface, are but the conditions necessary to adapt them to particular forms of service in the body.

Articulations.

Any place in the body where two or more bones meet is called an articulation, or joint. Such places are necessary both for the different movements of the body and for the development of the skeleton. Articulations are divided with reference to their freedom of motion into movable, slightly movable, and immovable joints.

Most of the immovable articulations are found in the skull, where the projections of one bone interlock with those of another and the two are firmly united by a layer of connective tissue.

The best examples of joints that are slightly, but not freely movable, are found in the spinal column. Cartilaginous pads are found between the bodies of the vertebrae and these, because of their elasticity, permit of a slight bending of the column in all directions. These movements are secured, not by having one bone glide over the other, but by a compression of the cartilage which is relieved by a change of direction of the motion.

Structure of Movable Joints. By far the most numerous and important joints of the body are those that admit of motion. Their construction is such that the motion occurs easily and without friction. At the same time they are strong enough to endure great strain without dislocation of their parts. The materials employed in their construction, besides the bones, are chiefly connective tissue, cartilaginous tissue, and synovial membrane.

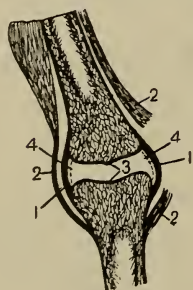


Fig. 26. General structure of a joint. 1. Ligaments. 2. Tendons. 3. Cartilage. 4. Synovial membrane.

At the joints the bones are usually enlarged and have specially formed projections, or depressions, which fit into corresponding depressions or elevations, on the bones with which they articulate. In addition to this the articular surface is quite smooth and dense, having no Haversian canals, and is covered with a layer of cartilage. Strong ligaments pass from one bone to the other

to hold each in its place. Some of these consist simply of bands, arranged with reference to the form of the joint, while others form continuous sheaths around the joints.

The interior of the joint, except upon the articular surfaces, is lined by a form of serous membrane, called the *synovial membrane*. This secretes a thick, viscid liquid, called the synovial fluid which prevents friction. The membrane passes completely around the joint and connects with the ends of the bones to form a closed sac in which the fluid is retained. Fig. 26.

Observation. Procure from the butcher shop the joint of some small animal (hog or sheep). Cut it open and locate the cartilage, synovial membrane, and ligaments. Observe the smoothness of the rubbing parts and the strength of the ligaments.

The Different Kinds of Movable Joints are designated as ball and socket, hinge, pivot, condyloid, and gliding.

In the *ball and socket* joint, the ball-shaped end of one bone fits into a cup-shaped cavity in the other bone, called the socket. The best examples are the hip and shoulder joints. This joint admits of motion in all directions.

In the *hinge* joint the bones are grooved and fit together after the manner of a hinge. Hinge joints are found at the elbows and knees and also in the fingers. The hinge joint gives motion in but two directions—backward and forward.

A *pivot* joint is formed by the fitting of a pivot-like projection of one bone into a ring-like receptacle of a second bone, so that one, or the other, is free to turn. A good example of the pivot joint is the junction of the radius with the humerus. The pivot joint admits of motion around an axis.

The *condyloid* joint is formed by the fitting of the ovoid end of one bone into the elliptical cavity of another bone. Examples of such are the knuckle joints and the joint of the wrist with the radius and ulna.

Gliding joints are formed by the articulation of plane surfaces. Examples of these are found in the articulations between the bones in the wrist and ankle. They are the simplest of the movable joints and enable one bone to glide upon the surface of another.

Hygiene. The efficiency of the body as a machine may be greatly impaired by lack of adjustment between its parts. If one part interferes with another, causing, for example, the compression of a blood

vessel or a nerve, disturbances arise that prevent the perfect functioning of the parts concerned. Since the skeleton serves as a framework for the body, the other parts are adjusted with reference to it. Any disturbance, therefore, of the natural position of the bones is likely to interfere with the adjustment of other parts as well. Particularly is this true of the spinal column, which serves both as a central axis and as a container of the spinal cord. A stooped position, or the peculiar lateral curve often assumed in writing, if long continued, leads to permanent distortion of the cartilaginous pads and causes an unnatural curvature of the spine. This, in turn, may throw important muscles, nerves, and blood vessels out of their natural positions. The habit of sitting and standing erect should, therefore, be formed early in life.

There is danger in childhood of bending the long bones of the body by improper use. Children who are made to walk before the bones have become stiff enough to support the weight are likely to bend the bones of the legs, causing the familiar "bow-legs." If children are made to sit on benches or chairs which are too high for the feet to reach the floor and which are not provided with supports for the feet, the thigh bones may be bent from having to support continuously the weight of the feet and lower legs.

Wholesome, nutritious food seems even more important to the development of the bones than to the other parts of the body. Where this is lacking a condition, known as "rickets," is frequently induced in which the bones become soft and are easily bent.

A *fractured bone* always requires the aid of a surgeon and no time should be lost in securing his services. In the meantime the patient should be placed in a comfortable position and the limb supported above the level of the rest of the body. While the fracturing of a bone is not a serious mishap, it is necessary that the very best skill be employed in setting it. Any failure to bring the ends of the bones into their normal relations, leads to permanent alterations and interferes with the proper use of the limb.

Dislocations of the larger joints also require the aid of the surgeon in their reduction, and sometimes in their subsequent treatment. Simple dislocations of the finger joints, however, may be reduced by pulling the parts until the bones can be slipped into position.

A *sprain* is an over-strained condition of the ligaments surrounding a joint and frequently requires very careful treatment. When

the sprain is at all serious a physician should be called. Because of the limited blood supply to the ligaments, they are very slow to heal and the temptation to use the joint before it has recovered is always great. Massage* judiciously applied to a sprained joint, by bringing about a more rapid change in the blood and lymph is frequently beneficial both in relieving pain and in hastening recovery.

Summary. Through the skeleton a suitable framework for a movable structure, the body, is provided. This supplies strength and stiffness to the different parts and aids in their various movements. The skeleton is adapted to its purposes through the number and properties of the individual bones, and through the manner in which they are connected. The joint is a special device for facilitating motion.

Review Questions. 1. State the purpose of the skeleton. What is the necessity for so many bones in its construction?

2. How may the per cent of animal and mineral matter in a bone be determined?

3. What properties are given to the bone by the animal matter? What by the mineral?

4. Locate the bone cells. What is their particular use in the bones?

5. What is the mechanical advantage of having certain bones hollow?

6. Give the uses of the periosteum.

7. State the purpose of the Haversian canals. Of the canaliculi.

8. What part does the spinal column play in the plan of the skeleton? Give its other functions.

9. Name the different materials used in the construction of a joint and the purpose served by each. What is the necessity for joints in the skeleton?

10. State the necessity for standing and sitting erect.

11. Account for the peculiar shapes of certain bones, as the ribs, the shoulder blades, the lower jaw bone, and the bones of the pelvic girdle.

* A process of gently rubbing, pressing, and kneading parts of the body with the hands.

CHAPTER XIV.

THE MUSCULAR SYSTEM.

Motion is the most noticeable attribute of the animal body. Not only can the body transport itself from place to place, but it is able to communicate motion to other bodies and, as we have seen, to carry on such internal movements as are essential to the vital processes. To provide for motion in the body, three well organized systems are required: 1. A system of supporting tissues which collectively form the skeleton. 2. A system of contractile elements, called the muscular system. 3. A system for controlling and co-ordinating the movements, known as the nervous system.

While the skeleton and nervous system are made to serve other important purposes in the body, the muscular system is applied almost exclusively to the production of motion. For this reason it is regarded as the *motor* system.

Muscular Tissue forms nearly one-half of the weight of the whole body and is, therefore, the most abundant of the tissues. This fact in itself indicates the importance of the problem of motion. The ability of muscular tissue to cause motion is primarily due to two properties—irritability and contractility. *Irritability* is the power of responding to a stimulus, that is, of becoming active when acted upon in certain ways. This property, which is especially marked in nervous and muscular tissues is due to the delicate organization of their protoplasm. *Contractility* is the property which enables muscle when stimulated, to draw up, or to become shorter and thicker (a condition called contraction) and, when the stimulus is withdrawn, to return to its former condition of relaxation.

Muscular tissue, depending upon the cells which make it up, is of three varieties, or types. These are the striated, or striped, muscular tissue, the plain muscular tissue, and the muscular tissue of the heart. A working group of muscular tissue is called a muscle.

The reddish muscle found in a piece of beef is a good example of striated muscle, while the clear ring surrounding the intestine of a cat (shown by a cross-

section) and the preparation from the cow's stomach, sold at the butcher shop under the name of tripe, are good examples of plain muscular tissue. The heart of any animal, of course, shows the heart muscle.

Structure of Striated Muscle. The cells of the striated muscles are slender, thread-like structures, varying in length from one-third of an inch to five inches, but having a diameter of less than one two-hundredths of an inch. Because of their great length they are called fibers. They are marked by a number of dark, transverse bands, called striations, which seem to divide them into a number of sections or disks. A thin, sac-like covering, called the sarcolemma, surrounds the entire cell and just beneath this may be seen a number of nuclei. Within the sarcolemma are still smaller fibrils and a semi-liquid substance, called the sarcoplasm. At each end the muscle cell tapers to a point from which the sarcolemma continues as a fine thread which, blending with other such threads, connects with the main tendon of the muscle. Most of the cells receive, at some portion of their length, the termination of a nerve fiber which penetrates the sarcolemma and spreads out as a sort of disk with several nuclei. This forms an important structure, known as the end plate.

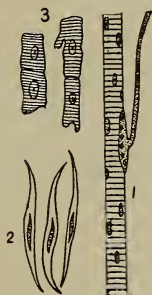


Fig. 27. Muscle cells.
1. A striated muscle cell with attached nerve fiber.
2. Non-striated cells. 3. Muscle cells of the heart.

Within the muscle the individual cells lie parallel and are surrounded with sheaths of connective tissue which bind them into separate bundles. These bundles are again bound into larger ones and the whole is surrounded by a single sheath of connective tissue which is called the *perimysium*. Between the parts of the muscle are numerous blood and lymph vessels and many small nerves.

The striated muscles are connected with the skeleton by white glistening cords, or bands, called *tendons*. The tendons are very strong and, by uniting with the periosteum of the bone at one end and with the perimysium and the fibrils from the muscle cells at the other, form very secure attachments.

Observation. Place a small muscle from the leg of a frog in a fifty per cent solution of alcohol and leave it there for half a day or more. Then cover with water, on a glass slide, and, with a couple of fine needles, tease out the small

muscle threads. Protect with a cover glass and examine with a microscope, first with a low and then with a high power. The striations, sarcolemma, and sometimes the nuclei and nerve plates may be made out in such a preparation.

The striated muscles in most warm-blooded animals, are reddish in color, due to the presence of haemoglobin. They are more or less rounded in form and as a rule are attached to the bones of the skeleton. For this reason they are called skeletal muscles. As most of them are under the control of the will, they are also called voluntary muscles. When stimulated they contract and relax quickly and with great force.

Structure of Non-Striated Muscles. The cells of non-striated muscles differ from those of striated muscles in being shorter and decidedly spindle-shaped, and in having a single well-defined nucleus. Furthermore, there is a lack of striations, the surface being smooth, and the connection with the nerve fibers is less marked. Fig. 27. They are also much smaller than the striated cells, being less than one one-hundredth of an inch in length and one three-thousandth of an inch in diameter.

Observation. Place a clean section of the small intestine of a cat in a mixture of one part of nitric acid to four parts of water and leave for four hours. Thoroughly wash out the acid with water and separate the muscular layer from the mucous membrane. Cover a small portion with water on a glass slide and tease out, with needles, until it is as finely divided as possible. Examine with a microscope, first with a low and then with a high power. The cells appear as very fine, spindle-shaped bodies.

In the formation of non-striated muscles the cells are attached to each other by a kind of muscle cement to form thin sheets or slender bundles. These differ from striated muscles in several particulars. They are of a pale, whitish color and are not attached to bones, but usually surround hollow cavities and tubes such as the stomach and intestines. They are not controlled by the will and contract and relax slowly.

Structure of the Heart Muscle. The cells of the heart combine the structure and properties of the striated and non-striated muscle cells and form an intermediate type between the two. They are cross-striped like the striated cells and are nearly as wide, but are quite short. Each cell has a well defined nucleus, but the sarcolemma is absent. Fig. 27. They are placed end to end to form fibers and many of the cells have branches by which they are united to the cells

in neighboring fibers. In this way they interlace more or less with each other, but are also cemented together. Muscular tissue of this variety seems excellently adapted to the work of the heart, and to this organ it is entirely confined.

The Muscular Stimulus. The inactive condition of a muscle is that of relaxation. It becomes active, or contracts, only when it is acted upon by some external influence, called a stimulus, and relaxes as soon as the stimulus is withdrawn. Muscles may be stimulated either directly or indirectly.*

In the body, the muscles are stimulated through the nerves whose connection with the muscle cells has already been noted. The nerves are supposed to transmit waves of force, called nervous impulses, which cause the contraction. (Chapter XVII.)

Liberation of Energy at the Muscle. The muscle is a kind of engine that does work by the transformation of potential into kinetic energy. Evidences of this are found in part in the changes that accompany contraction. Careful study shows that, during any period of contraction, oxygen and food material are consumed, waste products, as carbon dioxide, are produced, and heat is liberated.

The blood supply is also such that materials may be carried rapidly to and from the muscles. Blood vessels penetrate them in all directions and the capillaries lie very close to the individual cells. Moreover, provision is made through the nervous system whereby the flow of blood is *increased* when the muscle is at work. From these facts, as well as from the great force with which the muscle contracts, one must conclude that the muscle is a *transformer of energy*—that within its protoplasm, chemical changes take place whereby the chemical potential energy of oxygen and food substances is converted into the kinetic energy of motion.

The Plan of Using Muscular Force in the body is interesting from a mechanical, as well as from a physiological standpoint. Muscles exert force *only when they contract*. They can pull but not push. Hence in the body each muscle must work against some force that produces a result directly opposite to that which it produces. Some muscles work against the elasticity of certain parts of the body;

* If the muscles of a frog, in which the brain has been destroyed, be acted upon by a weak electric current, they may be made to contract, either by applying the current directly to the muscles or by stimulating the nerves that go to the muscles.

others to some extent against gravity; and others against pressure. But in most cases, *muscles work against muscles*. The striated or

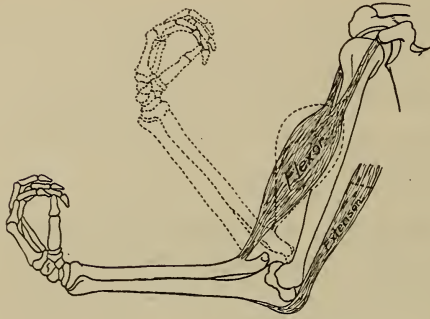


Fig. 28. Movements at the elbow. (Modified from Foster and Shore's Physiology for Beginners.)

skeletal muscles are nearly all arranged after this plan. As a rule a pair of muscles is so placed, with reference to a joint, that one moves the part in one direction and the other in the opposite direction. From the kinds of motion which they produce the skeletal muscles are classified as follows: 1. Flex-

ors and extensors. 2. Adductors and abductors. 3. Rotators. 4. Radiating and sphincters.

The flexors bend and the extensors straighten joints; the adductors draw the limbs toward the axis of the body and the abductors draw them away. The rotators (two kinds) twist and untwist joints; while the radiating muscles open and the sphincters close the natural openings of the body. Fig. 28.

Work of the Non-Striated Muscles. The non-striated muscles are found in the walls of the food canal and blood vessels. They are present in the trachea and bronchial tubes and also in the skin, where they are attached to the roots of hairs. While they do not contract so quickly or with so great force as the striated muscles, their work is more closely related to the vital processes. They propel the food through the alimentary canal, regulate the flow of blood through the arteries, and perform other acts of great importance in the maintenance of life.

Exchange of Muscular Force for Motion. The muscles contract with great force, but through short distances. It may be easily shown that the longest muscles in the body do not shorten more than three or four inches during contraction. To bring about the required movements of the body which, in some instances, amount to four or five feet, requires that a large part of the muscular force be

expressed as motion. This is accomplished by the attachment of the muscles to the bones which serve as levers.

A Lever may be described as a stiff bar which is used in lifting weights. It is made to turn on a fixed point of support, called the *fulcrum*. The force applied to the bar is called the *power*, and that which is lifted is termed the *weight*. Levers are of three kinds known as levers of the first, second, and third classes. These differ in the position of the power, weight, and fulcrum. In the lever of the first class the fulcrum is between the power and the weight. In the second class the weight is between the fulcrum and the power. In the third class the power is between the fulcrum and the weight. In all three classes the distance between the fulcrum and the power is called the *arm of the power* and the distance between the fulcrum and the weight is called the *arm of the weight*.

General Uses of Levers. In a mechanical sense, levers have three uses, as follows:

1. To change the direction of motion, that is, to enable a force acting in one direction to cause a movement in the opposite direction.
2. To exchange motion for force; illustrated by a small power, acting rapidly through a long distance, to move a great weight slowly through a short distance.
3. To exchange force for motion; illustrated by a great power, acting slowly through a short distance, to move a small weight rapidly through a long distance.

Experiments. With a stiff wooden bar, a spring balance, and a wedge-shaped fulcrum, show:

1. The position of the weight, the fulcrum, and the power in the different classes of levers and also the weight-arm and the power-arm.
2. The direction moved by both the power and the weight in the use of the different classes of levers.
3. That when the power-arm is longer than the weight-arm, the weight is greater but moves through a shorter distance than the power.
4. That when the weight-arm is longer than the power-arm, the power is greater and moves through a shorter distance than the weight.

Levers of the Body. In the body a bone usually serves as the stiff bar or lever, the muscle is the power, part of the body itself, or some object to be lifted, is the weight, while the fulcrum is generally, though not always, at a joint. The various body levers serve two main purposes:

1. They change the direction of the motion, that is, they enable

muscles acting in one direction to move parts of the body in an opposite direction.

2. They exchange force for motion, that is, they enable muscles acting through short distances to move portions of the body through long distances.

Of these two uses the latter is, for reasons already stated, the more important.*

Important Muscles. There are nearly 500 separate muscles in the body. These vary in size, shape, and plan of attachment, to suit their special work. Some of those prominent enough to be distinguished from the exterior of the body are as follows:

Of the head: The *temporal*, in the temple, and the *masseter*, in the cheek. These are attached to the lower jaw and are the chief muscles of mastication.

Of the neck: The *sterno-mastoids* which pass between the base of the skull and the sternum. They assist in turning the head and may be felt at the front of the neck.

Of the upper arm: The *biceps* on the front side, the *triceps* behind, and the *deltoid* at the upper part of the arm beyond the projection of the shoulder.

Of the forearm: The *flexors* of the fingers, on the underside, and the *extensors* of the fingers on the upper side.

Of the hand: The *adductor pollicis* between the thumb and other part of the hand.

Of the trunk: The *pectoralis major*, between the upper front part of the thorax and the shoulder, the *trapezius* between the back of the shoulders and the spine, the *rectus abdominis*, passing over the abdomen from above downward, and the *erector spinae*, found in the small of the back.

Of the hips: The *gluteus maximus* fastened between the lower back part of the hip and the upper part of the femur.

Of the upper part of the leg: The *rectus femoris*, the large muscle on the front of the leg which connects with the knee cap below.

Of the lower part of the leg: The *tibialis anterior* on the front side, exterior to the tibia, and the *gastrocnemius*, the large muscle in the calf of the leg. This

*Levers are not used in the body for increasing the *force* of muscles. The foot in lifting the body on tip-toe appears, at first thought, to be an exception to the rule and to increase the power of the muscle. If, however, the distance the body is raised be compared to the amount which the muscle shortens, it is found that the weight has moved farther than the power. This shows clearly that the force of the muscle is not increased. The foot in this movement corresponds more closely to a lever of the first class in which the ankle joint serves as a fulcrum and the earth is the weight. But since the earth is immovable the body is lifted in the same way that the fulcrum support is made to move when it is too weak to support the weight to be lifted.

is the largest muscle in the body, and is connected with the heel bone by the tendon of Achilles.

The use of these muscles in the body is, in most instances, easily determined by observing the results of their contraction.

The Hygiene of the Muscles is almost expressed in the word *exercise*. It is a matter of every-day knowledge that muscles are developed and strengthened by use and that they become weak, soft, and flabby through disuse. The fact that lack of exercise leads to disturbances in the vital processes is not, however, so generally understood. Voluntary exercise can be directly applied only to the skeletal muscles. But through the increased work of these, greater activity is required of the involuntary or plain muscles. In this way the vital processes such as the circulation and digestion are stimulated. For the same reason lack of exercise leads to a weakening of the involuntary muscles and a diminished efficiency of the vital processes. Exercise may therefore, be regarded as having a two-fold purpose: 1. That of building up and keeping in tone the muscular system. 2. That of improving the general health.

That muscular exercise may secure the best results from the standpoint of health, a number of conditions should be observed: 1. It should never be excessive or carried to the point of exhaustion. Severe muscular work is destructive both to the muscular and the nervous tissue. 2. It should, if possible, be of an interesting nature and taken in the open air. 3. It should be counteractive, that is, calling into play the parts of the body that have not been used during regular work. 4. It should be directed toward the weak rather than the strong parts of the body. 5. Where one is already tired from study or other work, it should be taken with moderation.

Summary. Motion is provided for in the body mainly through the contractility of muscle cells. These are grouped into working parts called muscles which in turn are attached to the movable parts of the body. The striated muscles, as a rule, are attached to the skeleton and bring about the voluntary movements of the body. The non-striated muscles surround the parts upon which they act and produce the involuntary movements. Both, however, are under the control of the nervous system which supplies the necessary stimulus. To increase the actual movement of the muscles they are in most instances attached to bones which serve as levers and which exchange muscular force for motion.

Review Questions. 1. What different systems are employed in the body in the production of motion? What is the special work of each?

2. If muscles could push as well as pull would so many be needed in the body? Why?

3. Locate a muscle which works against elasticity; one which works against pressure; one which to some extent works against gravity.

4. Locate five muscles that act as flexors; five that act as extensors; two that act as adductors; two as abductors; one sphincter; and one radiator.

5. How does the nervous system control the muscles?

6. Give differences in structure between the striated and the non-striated muscles. In what respect does heart muscle differ from both.

7. Give the general uses of the striated muscle in the body.

8. What are the proofs of the change of potential into kinetic energy during contraction.

9. What are the parts concerned in the physiological lever?

10. What is gained and what is lost by the use of levers of the third class in the body?

11. Why is one able to bite harder with the back teeth than with the front ones, when the same muscles are used in both cases?

12. Measure the distance from the middle of the palm of the hand to the center of the elbow joint. Find the attachment of the tendon of the biceps to the radius and measure its distance from the center of the elbow joint. From these distances calculate the force with which the biceps must contract in order to support a weight of ten pounds on the palm of the hand.

13. Show how contraction of skeletal muscle aids in the circulation of the blood and lymph.

14. How does the lack of sufficient exercise affect the general health?

15. Where exercise is taken for its effect on the general health, what conditions should be observed? Why?

CHAPTER XV.

THE SKIN.

Protective Coverings are found at all exposed surfaces of the body. They vary considerably, each kind being adapted to the conditions under which it serves. The more important ones are the skin which covers the entire external surface of the body, the mucous membrane which lines all the cavities that communicate by openings with the external surface, and the serous membrane which, including synovial membranes, lines all of the closed cavities of the body. Of less importance are the numerous connective tissue sheaths and membranes that surround different organs and tissues.

The Skin is one of the most complex structures of the body and has a number of functions in addition to that of protection. It is estimated to have an area of from 14 to 16 square feet and to have a thickness which varies from less than one-eighth to more than one-fourth of an inch. It is thickest on the palms of the hands and soles of the feet, the places where it is most exposed. It is made up of two distinct layers—an outer layer called the epidermis, or cuticle, and an inner layer called the dermis, or cutis vera.

The Dermis which is the thicker and heavier of the two layers, is made up chiefly of connective tissue fibers. These form a dense network which is the essential body of the skin and which gives the skin its toughness and elasticity. Imbedded in the connective

tissue are numerous blood and lymph vessels, oil and perspiratory glands, hair follicles, and nerves. Fig. 29.

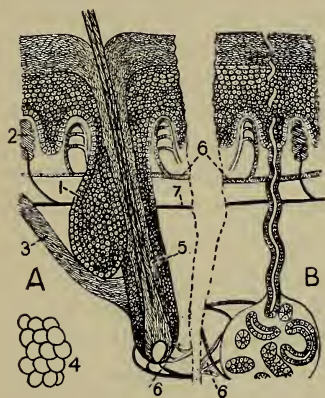


Fig. 29. The Skin. A. Hair follicle and adjacent structures. 1. Oil gland. 2. Touch corpuscle. 3. Muscle. 4. Cells of fat. 5. Hair shaft. 6. Blood vessels. 7. Nerve. B. A perspirary gland with duct opening at the surface. (Connective tissue not shown.)

On the outer surface of the dermis are numerous elevations, called papillae. These average about one one-hundredth of an inch in height and one two-hundred and fiftieth of an inch in diameter. They are most numerous on the palms of the hands, the soles of the feet, and the under surfaces of the fingers and toes. At these places they are larger and more closely grouped and form the parallel curved ridges that are readily seen. Each papilla contains the loop of a blood vessel and a small nerve, but many of them, in addition, are crowned with special nerve endings, called the *touch corpuscles*.

Observation. Examine the palm of the hand with a lens. Note the small ridges which correspond to the rows of papillae beneath. In these find small pits which are the openings of sweat glands. By counting the number of pits on a quarter of a square inch of surface, estimate the number on the entire palm of the hand.

The Epidermis is much thinner than the dermis. It is made up of several layers of cells which are flat and scale-like at the surface, but are rounded in form, and are filled with soft, granular protoplasm, where it joins the dermis. The epidermis is molded onto the dermis, filling up the depressions between the papillae and having corresponding irregularities. Neither blood nor lymph vessels are found in the epidermis, nourishment being derived from the lymph which reaches it from the blood vessels in the dermis. Only the part next to the dermis is made up of *living* cells. These are active, however, in the formation of new cells which take the place of those that are worn off at the surface. Some of these cells also contain the pigment granules which give the skin its characteristic color. The hair and the nails are important modifications of the epidermis.

A Hair is a slender cylinder, formed by the union of epidermal cells, which grows from a kind of pit in the dermis, called the hair follicle. The oval and somewhat enlarged part of the hair within the follicle is called the root, or bulb, and the uniform extension beyond the follicle is called the shaft. Connected with the sides of the follicles are the oil, or sebaceous, glands. These secrete an oily liquid which keeps the hair and cuticle soft and pliable. At the base of the follicles are small involuntary muscles whose contraction causes the roughened condition of the skin that occurs on exposure to cold.

A Nail is a tough, horny plate, which grows from a depression in the dermis, lined with active epidermal cells, called the *matrix*. The back part of the nail is known as the *root*, the middle convex por-

tion, the *body*, and the front margin the *free edge*. Material for the growth of the nail is derived from the matrix which is richly supplied with blood vessels. Cells added to the root cause the nail to grow forward and cells added to the under surface cause it to grow in thickness. The cuticle is joined to the nail around its entire circumference so that the covering of the dermis is everywhere complete.

Observations. 1. Examine the cuticle on the back of the hand and on the palm. At what place is it thickest and most resisting? Is it of uniform thickness over the palm? Try pricking it with a pin at the thickest places to see if pain is felt.

2. Examine a finger nail. Is the free edge or the root the thickest? Trim closely the thumb nail and the nail of the middle finger on one hand and try to pick up a pin from a smooth, hard surface. The result indicates what use of the nails? Name other uses.

3. Examine with a microscope, under a low power, the hair from a variety of animals, as the horse, dog, cat, etc., noting peculiarities of form and surface.

Functions of the Skin. The chief function of the skin is that of protection. It is enabled to perform this function by the connective tissue of the dermis, the tough non-sensitive epidermis, and the touch corpuscles with their connecting nerve fibers. The skin not only affords protection from mechanical injuries, but also from the action of chemicals and from the oxygen of the air. It also affords protection from the infectious disease germs that are everywhere present.

In addition to its work of protection, the skin serves as an organ of excretion (p. 88), and, to some extent, as an organ of absorption. It is also the most important organ of touch, or feeling, and is the chief agency in the regulation of temperature.

The Skin as an Organ of Adaptation. Forming, as it does, the boundary between the body and its physical environment, the skin is perhaps the most important agent through which the body is adapted to its surroundings. Evidence of this is found in the great variety of influences that are able to act on the nerves in the skin and in the changes which the cuticle undergoes on exposure. The most striking example of such adjustment, however, is seen in

The Regulation of Temperature. It is necessary to the continuance of life that the temperature of the body be maintained at a nearly uniform degree, known as the normal temperature, and which is 98.5° F. All are familiar with the voluntary efforts that are made through clothing, shelter, etc., to keep warm or cool as circum-

stances require. These efforts are stimulated by sensations of cold or heat which arise at the skin. In addition to this, *automatic* changes are stimulated which enable the skin of itself to act either as a means for getting rid of extra heat or for limiting its escape from the body.

The skin at all times is able to act as a *retainer of heat* because of the presence of fat within the dermis. This being a poor conductor of heat, acts as does a layer of clothing to prevent its escape.

The skin also assists in *cooling* the body. This it does by the radiation of heat from its surface, as from a stove, and by the evaporation of the perspiration.

Experiments. 1. Wet the back of the hand with water and move it through the air to hasten evaporation. Observe that as the hand dries, a sensation of cold is felt. Repeat the experiment, using alcohol or gasoline instead of water, noting the difference in effect. Alcohol and gasoline evaporate faster than water.

2. Wet the bulb of a thermometer with alcohol or water. Move it through the air to hasten evaporation. Note and account for the fall of the mercury.

The above experiments, which show that a liquid in evaporating absorbs, or takes up heat, illustrates the body's method of disposing of an excess of heat through the evaporation of the perspiration.

The Control of the Heat-Regulating Processes belongs to the nervous system. By changing the relative sizes of the arteries in the skin and the internal organs (p. 19) it is able to vary the amount of blood circulating in these places. At the same time it can vary the activity of the glands in the skin. Through the shifting of the circulation and by means of the changes in the activity of the perspiratory glands the temperature is kept practically uniform. Thus:

A *fall* in temperature is *prevented*; first, by diminishing the circulation in the skin where radiation of heat is rapid and increasing it in the internal organs where there is no radiation; and second, by diminishing the secretion of perspiration which causes loss of heat through evaporation.

A *rise* of temperature is *prevented*; first, by the blood being sent in large quantities to the skin where the heat can be radiated; and second, by increasing the quantity of perspiration which in turn requires more heat for its evaporation.

Alcohol, by interfering with the nervous control of the circulation, causes heat to be wasted at a time when the body should be saving it. If taken on a cold day, it increases the circulation in the skin and causes a *feeling of warmth*. This fact has given rise to the idea that alcohol acts as a heat producer in the body. While doing this to a

slight degree, its main effect is that of a heat dissipator. Arctic travelers have found that they withstand cold far better when no alcohol is used.

The Hygiene of the Skin is nearly all included in the problems of keeping it warm and clean. It is kept warm by clothing; bathing is the method of keeping it clean.

The *clothing* should be warm and loose fitting. Woolen goods are to be preferred to cotton because, being poorer conductors of heat, they afford better protection from cold. But woolen clothing fails to absorb the perspiration rapidly from the skin and to pass it to the outside where it is evaporated. This, together with its tendency to irritate, makes it objectionable for wearing next to the skin. If a thin layer of cotton clothing, however, is worn between the woolen clothing and the skin, these objections are obviated.

Bathing. One should bathe often enough to keep clean. The frequency will depend upon the season, the occupation of the individual, and the nature and amount of the perspiration. As to the kind of bath to be taken and the precautions to be observed, no specific directions can be given. These must be determined by the health and natural vigor of the individual. Care must be exercised at all times, however, to prevent too great an exposure of the body during the bath.

The cold bath has been found to have a beneficial influence on the general health beyond its direct effect upon the skin. When taken with care as to the length of time and the degree of cold, decided tonic effects may be produced on the general circulation and on the nervous system. The cold bath, taken just before retiring, is also an excellent aid in securing sound sleep during hot summer nights. Danger from the cold bath arises through the shock to the nervous system and the loss of heat from the body. It is avoided by using water whose temperature is not too low and by limiting the time spent in the bath. A brisk rubbing with a coarse towel should always follow the cold bath.

Treatment of Skin Wounds. Small skin wounds frequently become serious from getting infected by germs or "poisoned." A wound should be kept clean and if it shows signs of infection, should be washed with some antiseptic solution. Or, it may be washed with clean warm water and then covered with some antiseptic ointment of which there are a number on the market.

A solution of carbolic acid in water (three parts of carbolic acid to one hundred parts of water) is an excellent antiseptic wash. It may

be used not only for the cleansing of skin wounds, but also in counteracting the poisonous effects that follow the bites of insects.

Summary. The skin forms the external protective covering of the body and also serves additional purposes. It is the most important agency in adapting the body to its physical surroundings as shown by the part which it plays in the regulation of temperature.

Review Questions. 1. Give an example of each of the protective coverings of the body.

2. Compare the dermis and the epidermis with reference to thickness, composition, and functions.

3. To what is the color of the skin due? How is color affected by sunlight?

4. What different kinds of epidermis are found on our bodies? What kinds on the body of a chicken?

5. What provision is made in the skin for each of its different functions?

6. How does perspiration cool the body?

7. What changes occur in the skin when the body is in danger of becoming too warm? When in danger of becoming too cold?

8. Discuss the necessity for the body's adapting itself to external conditions.

9. How does alcohol make one *feel* warm when he is losing heat?

10. What precautions should be observed, by one in poor health, in taking a bath?

CHAPTER XVI.

PLAN OF THE NERVOUS SYSTEM.

General View. If all the other tissues of the body were removed, leaving only the nervous, there would still remain a skeleton outline of the body.

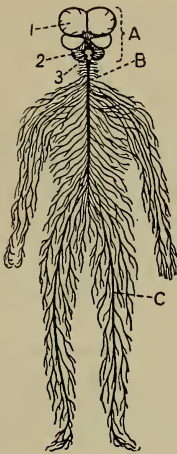


Fig. 30. The nerve skeleton. A. Brain. 1. Cerebrum. 2. Cerebellum. 3. Medulla oblongata. B. Spinal cord. C. Sciatic nerve.

Observation of such a nerve skeleton shows a central axis which is made up of two parts, the brain and the spinal cord. From the central axis white, cord-like structures emerge and pass to different parts of the body. These are the nerve trunks, and the smaller branches into which they divide are the nerves. The nerves also undergo division until they terminate as fine threads in all parts of the body. The distribution of nerve terminals, however, is not uniform as might be supposed, but the skin and important organs, like the heart and stomach are the more abundantly supplied. Situated along the course of many nerves are small enlargements, called ganglia, and from these also small nerves emerge. At certain places the small nerves and ganglia are so numerous as to form a kind of network, or *plexus*. All these parts—brain and cord, nerve trunks and nerves, ganglia and nerve terminals—taken together, constitute the nervous system. Fig. 30.

Dissection of the Nervous System. For this purpose a half grown cat is generally the best available specimen. This should be killed with chloroform and secured to a board as in the dissection of the abdomen. (P. 53.)

Open the abdominal cavity and remove its contents, tying the alimentary canal where it is cut, and washing out any blood which may escape. Dissect for the nervous system in the following order:

1. Cut away the front of the chest, exposing the heart and lungs. Find on each side of the heart a nerve which passes by the side of the pericardium to the diaphragm. These nerves assist in controlling respiration, and are called the *phrenic* nerves. Find other nerves going to the different organs in the thorax.

2. Remove the heart and lungs. Find in the back part of the thoracic cavity on each side of the spinal column a number of small "knots" of nervous matter joined together by a single nerve. These are the sympathetic ganglia. Where the neck joins the thorax, find two sympathetic ganglia much larger than the others.

3. Cut away the skin from the upper side of the shoulder and fore leg. By separating the muscle and connective tissue where the leg joins the thorax find several nerves of considerable size. These connect with each other, forming a network called the *brachial plexus*. From here nerves pass to the thorax and to the fore leg.

4. From the brachial plexus trace out the nerves which pass to different parts of the fore leg. In doing this separate the muscles with the fingers and cut only where necessary to expose the nerves. Note that some of the branches pass into muscles while others connect with the skin.

5. Remove the skin from the upper part of one of the hind legs and separate the muscles carefully until a large nerve is found. This is one of the divisions of the *sciatic* nerve. Carefully trace it to the spinal cord, cutting away the bone where necessary, and find the branches where it joins the cord. Then trace it toward the foot discovering its branches to different muscles and to the skin.

6. Unjoint the neck and remove the head. Examine the spinal cord where exposed. Cut away the bone sufficiently to show the connection between the cord and one of the spinal nerves. On one of the roots of the nerve, find a small ganglion.

7. Fasten the head to a small board and remove the scalp. Saw through the skull bones in several directions. Pry off the small pieces of bone so as to show the upper part of the brain. Study its membranes, convolutions, and divisions.

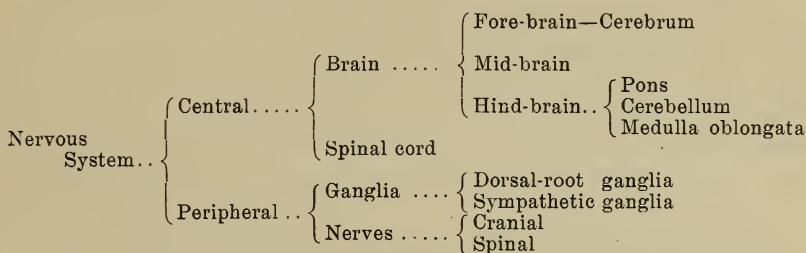
8. With a pair of nippers break away the skull until the entire brain can be removed from its cavity. Examine the different divisions, noting the relative position and size of the parts.

9. With a sharp knife cut sections through the different parts of the brain to show the position of the "gray" and the "white" matter.

NOTE.—If the entire class is to examine the same specimen, it is generally better to have the dissecting done beforehand and the parts separated and tacked to small boards. This will permit of individual examination. Sketches of the sciatic nerve, brachial plexus, the general form of the brain, and of sections through its different parts should be made by the pupils.

A dissection of the nervous system, carried out by the aid of the microscope in great detail, shows it to be perfectly continuous throughout the body and to be made up of different varieties of the same structural element.

Divisions of the Nervous System. While the nervous system is everywhere closely connected, it may for purposes of study be regarded as made up of parts which are more or less distinct from each other. The classification generally adopted for this purpose is the following:



The Central Nervous System. This division of the nervous system lies within the cranial and spinal cavities and consists of the brain and spinal cord. While the brain occupies the cranial cavity and the spinal cord the spinal cavity, they connect with each other through the large opening at the base of the skull to form a single continuous structure. The central division is the more complicated portion of the nervous system and the part most difficult to understand.

The Brain, which is the largest mass of nervous tissue in the body, weighs in the average sized man about 50 ounces and in the average sized woman about 44 ounces. It is made up of three parts which are named from their positions the fore-brain, the mid-brain, and the hind-brain.

Fig. 31.



Fig. 31. Relations of the divisions of the brain. A. Cerebrum. B. Mid-brain. C. Pons. D. Cerebellum. E. Medulla oblongata. I. The fore-brain. II. The hind-brain.

The *fore-brain* consists chiefly of a single part, known as the *cerebrum*. This comprises about seven-eighths of the entire brain and occupies all the front, middle, upper, and back portion of the cranial cavity, spreading over and concealing, to a large extent, the parts beneath. It presents a large surface covered with ridge-like convolutions, between which are deep but narrow depressions, called fissures. The cerebrum consists of two ex-

actly similar divisions, the *cerebral hemispheres*, which are separated by a deep, longitudinal groove, called the median fissure.

The *mid-brain* is a short, rounded, and compact body that lies immediately beneath the cerebrum and connects the fore-brain with the hind-brain.

The *hind-brain* lies beneath the back portion of the cerebrum and occupies the posterior enlargement at the base of the cranial cavity. It forms about one-eighth of the entire brain and is composed of three parts—the cerebellum, the pons, and the medulla oblongata. The cerebellum is a flat and somewhat triangular structure whose upper surface fits into the concave under-surface of the back part of the cerebrum. It weighs about two ounces. In general form and structure, it resembles the cerebrum, but it differs therefrom in being more compact and in having its surfaces covered by narrow transverse ridges that lie parallel to each other. The *pons*, or pons Varolii, named from its resemblance to a bridge, is situated directly in front of the cerebellum and is easily recognized by a circular expansion extending forward from the cerebellum. It consists largely of the nerve fibers that connect with different parts of the cerebellum. The *medulla*, or medulla oblongata, is, properly speaking, an enlargement of the spinal cord within the cranial cavity. It is somewhat triangular in shape and lies immediately beneath the cerebellum. Its structure is different from that of the cord and it contains important groups of cell-bodies, or nerve centers.

The Spinal Cord averages about seventeen inches in length and is about two-thirds of an inch in diameter. It does not occupy the entire spinal cavity, but terminates at the lower part of the first lumbar vertebra. It connects at its upper end with the medulla and terminates at its lower extremity in a number of large nerve roots which are continuous with the nerves of the hips and legs.

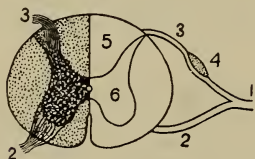


Fig. 32. Section of spinal cord at the place of union with a pair of spinal nerves. The left side suggests the structure. 1. Spinal nerve. 2. Anterior roots containing efferent fibers. 3. Posterior roots, containing afferent fibers. 4. Spinal root ganglion. 5. White matter of cord. 6. Gray matter. (Modified from Thornton's Human Physiology.)

all of which are connected with the central division.

The Peripheral Division of the nervous system includes all the nervous structures found outside the brain and cord. These consist of the cranial and the spinal nerves and of various ganglia,

The *spinal nerves* pass from the spinal cord to different parts of the body, leaving the spinal cavity through small openings between the vertebra. They consist of thirty-one pairs and each nerve joins the cord by two roots—a ventral or anterior root and a dorsal or posterior root. On the dorsal root of each spinal nerve is a small ganglion which, named from its position, is called the *dorsal root ganglion*.

The *cranial nerves* are those which branch from the brain. There are twelve pairs of these and they are numbered in the order in which they connect with the under side of the brain. The pair nearest the front is called the first pair: the next in order the second pair, and so on. Unlike the spinal nerves, the cranial nerves present great variation and, because of their relation to the special senses, some of them are of particular importance.

Distribution of the Cranial Nerves. 1. The first pair (Olfactory) are the nerves of smell and connect the brain with the mucous membrane of the nose.

2. The second pair (Optic) connect with the retina of the eye and are the nerves of sight.

3. The third, fourth, and sixth pairs (*Motores oculi*) connect with the muscles of the eyeballs and control their movements.

4. The fifth pair (Trigeminal) connect with the skin of the face, the muscles of mastication, the mucous membrane of the mouth, and the front of the tongue and have various functions.

5. The seventh pair (Facial) connect with and control the muscles that give expression to the face.

6. The eighth pair (Auditory) connect with the internal ear and are the nerves of hearing.

7. The ninth pair (Glossopharyngeal) connect with the surface of the back part of the tongue and with the muscles of the pharynx.

8. The tenth pair (Vagus) connect with the heart, larynx, lungs, liver, and stomach.

9. The eleventh pair (Spinal accessory) connect with the muscles of the neck.

10. The twelfth pair (Hypoglossal) connect with the muscles of the tongue.

The Sympathetic Ganglia are found in different parts of the body and vary in size from those which are half an inch in diameter to those that are smaller than the heads of pins. The largest and most important ones are found in two chains which lie in front and a little to either side of the spinal column and reach from the neck to the region of the pelvis. The number of ganglia in each of these chains is about twenty-four. They are connected by the right and left sympathetic nerves which pass vertically from one ganglion to the other.

In addition to these ganglia, important ones are found in the head (outside of the cranial cavity) and in the plexuses of the thorax and abdomen. The sympathetic ganglia receive nerves from the central nervous system, but connect with glands, blood vessels, and the intestinal walls through nerves which pass from them.

Protection of Parts. To shield successfully such delicately organized structures as those of the nervous system, requires a variety of protective agencies. The nerves and ganglia outside of the brain and cord are protected by the sheaths that inclose them and by the tissues by which they are surrounded. The larger ones are deep-seated, as a rule, and occupy localities that are shielded by the bones.

The brain and cord require special provisions for their protection. In the first place the cavities in which they lie are completely surrounded by bones which not only shield them from the direct effect of physical force, but by their peculiar construction prevent the passage, to a large degree, of jars and shocks to the parts within. In the second place, they are surrounded by three separate membranes, as follows: 1. The *dura*, or *dura mater*, a thick, dense, tough membrane which lines the bony cavities. 2. The *pia*, or *pia mater*, a thin, delicate membrane, containing numerous blood vessels, that covers the surface of the brain and cord. 3. The *arachnoid*, a membrane of loose texture, that lies between the *dura* and the *pia*.

Finally, within the spaces of the *arachnoid*, is a lymph-like liquid which completely envelops the brain and cord and which, by acting as a watery cushion, protects them from jars and shocks. Thus the brain and cord are directly shielded by the bones, by membranes, and by the liquid which surrounds them. They are further protected from the jars and shocks incident to the movements of the body by the general elasticity of the skeleton.

The Structural Elements of the nervous system are the nerve cells, or neurones.* These differ greatly in form and appearance from the other cells of the body and also to a marked degree among themselves. The majority of them consist of three distinct parts known as the cell-body, the dendrites, and the axone.

* In 1891 Waldeyer advanced the idea that the nervous system was made up of, and its work carried on by, separate and distinct units which were all of the same kind. To designate this common nervous element he proposed the term *neurone*. This includes the cell body, the dendrites, and the nerve fiber, and is synonymous with nerve cell as the term is used in this book. Waldeyer's idea, known as the "neurone theory," has been generally accepted.

1. *The cell-body* has in itself the form of a complete cell and was at one time so described. It consists of a rounded mass of protoplasm, containing a well defined nucleus. This protoplasm is similar to that of other cells but is characterized by the presence of many small granules that are easily stained in the preparation of slides for microscopic study.

2. *The dendrites* are short extensions from the cell-body. They branch as do the roots of a tree and form in many instances a complex network of tiny rootlets. Their protoplasm like that of the cell-body is more or less granular. The dendrites increase greatly the surface of the cell-body, to which they are closely related in function.

3. *The axone*, or nerve fiber, is a long, slender process which connects the cell-body with some remote organ or tissue. It was at one time thought to be a distinct nerve element in itself, but a study of the early development of the nerve cell as well as the observed continuity of the parts has shown it to be an outgrowth from the cell-body.

The Typical Nerve Fiber, or axone, is made up of three parts. The inner or central part is called the *axis cylinder*. This is the essential part of the fiber and is the only part continuous with the protoplasm of the cell-body. Surrounding the axis cylinder is a layer of substance, white in color and of an oily consistency, known as the *medullary*, or myelin, sheath. On the outside and completely surrounding the medullary sheath, is a thin layer called the *primitive sheath*, or neurilemma. This is made up of a single layer of cells which form wide, but separate and distinct bands around the fiber. Fig. 33.

In certain fibers branches pass off at intervals at right angles from the main part. These by distributing themselves in

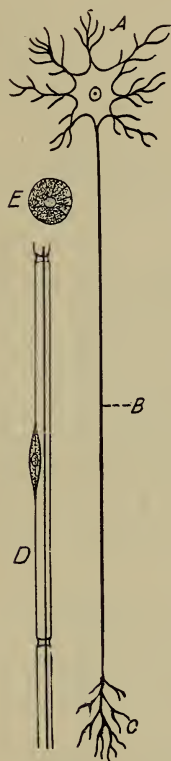


Fig. 33. Parts of a typical nerve cell, or neurone. A. Cell body with projecting dendrites. B. Nerve fiber. C. Fiber termination. D. Enlarged portion of fiber, showing the axis cylinder and its enveloping sheaths. E. Cross section of fiber still more enlarged.

a manner similar to the first, greatly extend the influence of a single neurone.

The fibers vary, among the different cells, from less than one one-hundredth of an inch to more than three feet in length.

Arrangement of the Structural Elements. Neurones never exist singly in the body, but are massed together to form the active structures of the nervous system. Their general arrangement in different parts is as follows:

1. *In simple nerves and ganglia.* The nerves contain the fibrous portions of the neurones. These lie parallel with each other and are embedded in a connective tissue support, called the *epineurium*. In the nerve trunks and in the large nerves, the fibers are separated into bundles. Somewhere along the course of every nerve are to be found the cell-bodies belonging to its fibers. These may form one of the various small ganglia of the body or only a part of some large ganglion. The simple ganglion is but a cluster of cell-bodies and their accompanying structures.

2. *In the brain and cord.* These parts are made up of both nerve fibers and cell-bodies. They may be regarded as a combined mass of nerves and ganglia so dense as to be inseparable from each other. The gray matter, observed in sections, consists chiefly of cell-bodies while the white matter is made up largely of fibers. In the cerebrum and cerebellum the cell-bodies are found mostly in the layer of gray matter at the surface. From here the fibers pass through the white matter to various places, connecting with other portions of the brain surface or with other divisions of the brain and cord. Finally certain ones pass, as parts of nerves, to places outside of the cranial and spinal cavities.

In the spinal cord the cell-bodies occupy the central gray column, while their fibers pass upward or downward through the white matter or extend through the spinal nerves to different parts of the body. In the medulla, pons, and mid-brain the cell-bodies are collected into groups from which the fibers extend to other parts.

Connection of the Neurones with Each Other. The method of connection of the neurones for their work in the body is that of a loose, end-to-end union. The fiber branches of one cell, terminate among the dendrites of other cells and these in turn send their fibers into the dendrites of other cells. There are thus formed, through the contiguous nerve cells, great numbers of continuous nerve paths

through the body, which bring all parts of it into connection with the brain and cord. Fig. 34. The terminal cells in these nerve chains

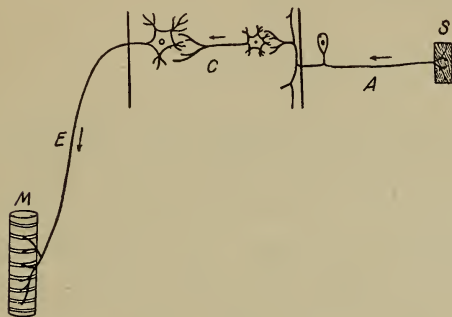


Fig. 34. Diagram of a nerve path connecting the skin with muscles. A. Afferent nerve cell. C. Intermediate cell of the brain or cord. E. Efferent cell. End organs are found at S and M. The arrows show the direction of the nervous impulses.

usually connect with special contrivances, called *end-organs*, of which the touch corpuscles are examples. For this reason the left side of the brain is connected with the right side of the body and vice versa—a fact which accounts for an injury to one side of the brain causing paralysis on the opposite side of the body. Most of the crossing occurs within the medulla.

Summary. The nervous system is made up of similar structural elements called nerve cells or neurones. These are the active agents in all parts of the system and connect every portion of the body with the central nervous mass, consisting of the brain and cord. As a whole the nervous system may be compared to a highly developed and very complicated system of telegraphy, in which the nerves correspond to the wires and the brain and cord to the central stations.

Review Questions. 1. What different structures are to be seen in a skeleton outline of the nervous system?

2. Describe briefly the cerebrum, cerebellum, medulla, and spinal cord.
3. Enumerate the different agencies employed in the protection of the brain and cord.
4. State some of the differences between nerve cells and the other cells of the body.
5. Sketch a complete nerve cell or neurone, and name its parts.
6. Describe the general arrangement of the neurones in the different divisions of the nervous system.
7. Account for the differences in color to be seen in sections of the brain and cord.

CHAPTER XVII.

WORK OF THE NERVOUS SYSTEM.

In a complex organism, such as the body, where the work done by each part must contribute to the general work of all, there must be unity and harmony of action. Each organ must act in the right manner and at the right time and there must be complete co-operation among the organs whose functions are related. The securing of such action is termed *co-ordination* and this is a function of the nervous system. Briefly stated the work of the nervous system is to control and co-ordinate the activities of the body.

Properties of Nerve Cells. The two properties of the nerve cells upon which their work chiefly depends are irritability and conductivity. The property of *irritability* was explained in the study of the muscles. (P. 104.) Nerve cells respond more readily to the action of stimuli and are therefore more irritable than are muscle cells. Moreover, all the stimuli which cause muscular contraction, and others besides, may induce activity of the nerve cells. They are by far the most irritable portions of the body.

Conductivity is the property by which the effect of a stimulus is transferred from one part of a nerve cell to another. If any part of the nerve cell is acted on by a stimulus, the disturbance which it sets up is conducted or transmitted to all other parts of the cell. This wave-like spreading of the nervous disturbance is termed the *nervous impulse*.

A third property—that of releasing through oxidation a form of energy which may cause or re-enforce the nervous impulse—is frequently attributed to the cell. While there are many reasons for believing in the existence of this property, and it is difficult to explain certain activities of the nervous system without it, its actual presence is difficult to prove.

The Nature of the Impulse is that of a wave which starts at the place of irritation in the nerve cell and moves through the protoplasm wherever continuous paths for it are found.

The class of waves to which the impulse belongs is difficult to determine. At different times it has been regarded as a current of electricity, as a progressive chemical change, as a moving vibration like that on a stretched rope, and as a molecular disturbance, accompanied by an electrical discharge. It has been shown to be different from the first three types of waves, and the last named theory has but recently been proposed.* The velocity of the nervous impulse has been shown to be about one hundred feet per second.

Purpose of the Nervous Impulse. The nervous impulse is the means employed for controlling and co-ordinating the different parts of the body. It is the stimulus which the nerve cells apply to all the active parts of the body, including muscle cells, gland cells, and *other nerve cells*. The impulse seems able to produce two distinct effects; first, to throw resting organs into action and to increase the action of organs already at work; second, to diminish the rate or check entirely the activity of organs. Impulses producing the first effect are called *excitant* impulses; those producing the second, *inhibitory* impulses. There is reason, however, for believing that impulses produce only the first effect and that the observed inhibitory action is but an indirect result of excitant impulses.

Functions of the Parts of the Nerve Cell. The cell-body serves as a nutritive center from which the other parts are supplied with nourishment. Proof of this is found in the fact that when any part of the cell is separated from the cell-body it dies, while the cell-body and the remaining parts continue to live. In addition to this the cell-body probably re-enforces the nervous impulse.

The dendrites serve two purposes: First, they extend the surface of the cell-body and enable it to absorb a greater amount of nourishment from the surrounding lymph. Second, they act as receivers of stimuli from adjacent cells.

The special function of the nerve fiber is to transmit the impulse. By its length, structure, and property of conductivity it is especially adapted to this work. The axis cylinder, however, is the only part concerned in the transmission. The primitive and medullary sheaths protect the axis cylinder and, according to some authorities, serve also to insulate it.

* *Theory of Mathews, 1902.* The nature of the nervous impulse is that of a wave of temporary coagulation that sweeps along the nerve fiber and gives rise to an electrical discharge which is the stimulating agent.

Action of Nerve Stimuli. Nerve cells, like the cells of muscles, are dependent for their activity upon external stimuli. These, in a general way, may be divided into two classes—a class which acts upon the nervous system from the outside (external) and a stimulus supplied by the nerve cells themselves.

The external stimuli are of various kinds. They include mechanical forces, temperature changes, chemical reagents, sound waves, electrical currents, and rays of light. They may act upon the body from the surface or from within the tissues. Moreover, through the connection of a special class of nerve cells with the skin, the mucous membrane, and other parts of the body, and through the joining of their fiber terminations with small bodies called the sense-organs, the whole nervous system is made peculiarly susceptible to the action of the various stimuli. In other words, the arrangement is such that the nervous system is subjected at all times to stimulation from the outside. In this way it is kept, to some degree, continuously active.

So far as known, the only stimulus furnished by the nerve cells is the nervous impulse. An impulse traversing the protoplasm of one cell, is able to start new impulses in the cells with which it makes connection. The excitation is effected through the dendrites which are contiguous with the terminations of the fiber that bears the impulse. This enables a series of impulses to be produced along a given nerve path and causes the effect of an external stimulus to be passed to remote parts of the body. The method of transmission, by the nerve cells, of the effect of an external agent is finely illustrated in

Reflex Action. When the nervous system receives a sudden and strong stimulus, an immediate response is frequently observed in the movement of some part of the body. The jerking away of the hand on accidentally touching a hot stove, the winking of the eyes when suddenly exposed to danger, and the quick movements from electrical shocks are familiar examples. Since in many cases the effect seems to be turned back toward the originating cause these actions are termed reflex. The part of the nervous system involved in simple reflex actions is shown as follows:

A live frog from which the brain has been removed, is suspended with its feet downward and free to move. If a toe is pinched, the foot is drawn away and if dilute acid, or a strong solution of salt, is placed on the tender skin, the feet are moved as if to take away the irritating substance. If, however, the spinal cord be also destroyed, the movements no longer follow irritations of the skin.

The experiment shows that while reflex actions may take place independently of the brain they cannot take place independently of some part of the central nervous system.

Reflex Action Paths. Following the course of any nervous discharge which results in reflex action, the following divisions are easily made out: 1. A pathway reaching from the surface of the body, or place of irritation, to the central nervous system. This is called the *afferent* pathway. 2. A pathway through the central system. 3. A pathway which leads from the central system to the active tissues of the body, known as the *efferent* pathway. Figs. 34 and 35.

The cells which form these pathways, present important differences and must be considered somewhat in detail.

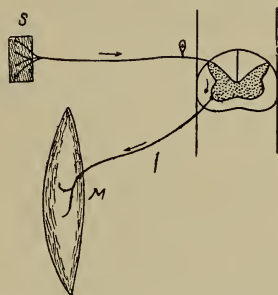


Fig. 35. Diagram of a reflex action pathway.

afferent fibers form the greater portions of the posterior roots of the spinal nerves.*

The cells that form the central pathways are called *intermediate* cells. They are similar in form to the efferent cells, but as a rule, have shorter fibers.

The cells that convey impulses away from the brain and cord are called *efferent* cells. Their cell-bodies lie in the gray matter of the brain and cord and are well supplied with dendrites. Their fibers are long and pass to different parts of the body. Those from the cord form the anterior roots of the spinal nerves. Fig. 32.

Kinds of Nerve Cells. The cells that convey impulses toward the brain and cord are called *afferent* cells. The cell-bodies of such of these as join the spinal cord, are located in the spinal root ganglia. They send out short fibers which soon separate into two branches—one of which passes to the surface of the body, while the other enters the spinal cord and there separates into an ascending and a descending branch. The

*In 1811 Charles Bell discovered that the posterior roots of the spinal nerves

The Cells of the Sympathetic Ganglia complete the efferent pathways to the organs of circulation and the viscera. They also serve to extend the influence of the efferent cells over a larger area. For example, a single efferent cell, by its branches, may stimulate a large number of the sympathetic cells each of which will, in turn, stimulate the cells of muscles or glands. Because of this function the sympathetic cells, are called *distributing* cells. Since the direction of their impulses is from the central system they are also classed as efferent cells.

Order of Stimulation. In any reflex action the parts concerned are stimulated in a definite order which is as follows: First, some external stimulus, acting strongly on their fiber terminals, starts impulses in the afferent cells. These pass to the central system and act as stimuli to the central or intermediate cells. These, through their impulses, now stimulate the efferent cells and they in turn act in the same way on the muscles. Fig. 34.

Purpose of Reflex Action. If the student will carefully note and study the reflex actions of his own body for a period, say of two weeks or longer, he must conclude that they all serve the common purpose of protection—that through their agency portions of the body in danger are removed to places of safety. Furthermore, the speed with which this is accomplished is so great that the position of safety is reached before one is aware of the danger. While these movements are sometimes unnecessary and often fail of their purpose, they must be regarded as a protective agency of the greatest importance.

A Larger View of Reflex Action, however, must be taken. It represents the *ordinary* method of reaction of the involuntary organs, proofs of which are easily found. A case in point is the secretion of saliva when food is present in the mouth. The pressure of food against the mucous membrane starts the nervous reactions and these passing through the medulla, reach and stimulate the salivary glands. Again on sudden exposure to cold, the little arteries going to the skin quickly diminish in size, check the normal flow of blood to the skin, and prevent too great a loss of heat. In this case the nervous reactions,

contain afferent, or sensory fibers, while the anterior roots contain efferent or motor fibers. This discovery showed each spinal nerve to be double in function.

Tracing the fibers of the posterior roots they are found to be distributed chiefly to the skin, while those of the anterior go chiefly to the muscles and to the sympathetic ganglia.

starting at the surface of the body, have been transmitted through the central system and through efferent and sympathetic cells, to the muscles in the walls of the arteries. Other illustrations of the reflex nature of involuntary actions are found in the swallowing of the food, and in changes of the blood supply to different organs.

A fact of even greater importance, however, is that *all* the activities of the body, including the so-called voluntary actions, are in nature reflex. By this statement is meant that the primary causes of any and all action are to be found outside of the nervous system, that these on being impressed upon the nervous system, start the reactions which finally reach the organs that give them expression. Ordinarily, however, the term reflex is employed in the restricted sense in which it has been discussed.

Voluntary Actions comprise those movements of the body of which we are conscious and which seem to be controlled by a certain influence designated the will. In some respects they may be regarded as a higher order of reflex action, or as reflex actions modified by the mind. The specific action of the mind in these movements is not understood. The final result, however, is to so modify the natural reflexes that the effect of a given stimulus cannot be foretold. Reactions to produce voluntary movements must take place *through the cerebrum*. To this organ afferent pathways, from all parts of the body, may be traced and from it efferent pathways extend, through nerve fibers, to all the voluntary muscles.

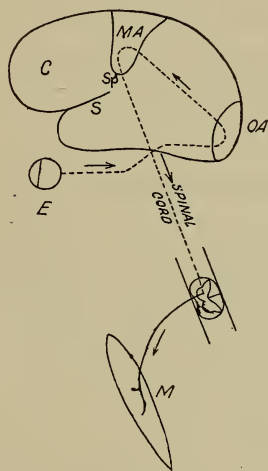


Fig. 36. From the eye to the muscles in voluntary motion. E. Eye. OA. Sight area. MA. Motor Area. Sp. Speech area. S. Hearing. Arrows show direction of the impulses.

Automatic Action. Everyday experience teaches that any nervous reaction becomes easier by repetition. A given act performed a number of times under conscious direction, establishes a nervous condition which enables the act to occur without such direction. That is to say, the parts concerned in causing the act have become automatic, or self-acting.

Within the nervous system are many automatic mechanisms, some of which, like the regulation of the heart-beat, are *natural*, while others, as the motion of the hand in writing, have been acquired.

The development of automatic mechanisms, probably consists in the establishment of special reaction pathways in the nervous system. Through the branching of the nerve fibers, many pathways are open to any given nervous discharge. If, however, the discharge is constantly guided in a particular path, as in the doing of a specific act, this becomes in time the natural outlet, and will be the one followed when there is no conscious interference. When this is accomplished, it is simply necessary that a given stimulus start the reaction. This acting reflexively and following the established pathway, will reach the right destination and produce the desired result independently of other causes.

Habits. In addition to the automatic activities that involve parts of the body only and relate to specific acts and processes, there is a class of automatic activities that involves the body as a whole. These are known as habits. Habits are acquired conditions of the nervous system that enable given stimuli to prompt definite and far-reaching results. They are also acquired by repetition and, in common with other automatic activities, serve the important purpose of economizing the nervous energy. However, if pernicious habits are formed instead of those that are useful they are detrimental both from a physical and a moral standpoint.

Functions of the Parts of the Nervous System. The relationship between the different parts of the nervous system is, as a rule, too close to ascribe specific duties to particular divisions. In a general way it may be stated: 1. That the gray matter in the spinal cord, medulla, pons, and mid-brain are concerned in the reflex actions of the different parts of the body. 2. That the cells in all these places, in addition to responding to stimuli from the surface of the body, are also connected with and are subordinate to nerve cells in the cerebrum and cerebellum. 3. That the reflex centers in the medulla, because of their controlling influence upon respiration, circulation, and the secretion of liquids, are of special importance in the maintenance of life.

Efforts to discover some *special* function of the cerebellum have been, in the main, unsuccessful. Its removal from small animals instead of producing definite results usually interferes in a mild way

with a number of activities. The most noticeable results are a general weakness of the muscles and an inability on the part of the animal to balance itself. While it seems closely related to the voluntary movements of the body, its relation to other parts of the nervous system, also concerned in these movements, is not understood.

Functions of the Cerebrum. While the work of the cerebrum is also closely related to the work of the general nervous system, it, more than any other part, exercises functions peculiar to itself. As already noted, nervous reactions that occur through the cerebrum are so modified as to lose, in many cases, their apparent relation to external stimuli. This power to postpone, or entirely inhibit, nervous reactions is but a part of the general work ascribed to the cerebrum as the "organ of the mind." Numerous experiments performed on the lower animals, together with observations on man, show the cerebrum to be the seat of the mental activities and to make possible, in some way, the processes of consciousness, memory, volition, imagination, emotion, thought, and sensation.

Localization of Cerebral Functions. Many experiments have been made in order to determine whether the entire cerebrum is concerned in each of its several activities or whether special functions belong to different parts. These experiments have been performed upon the lower animals and the evidence thus obtained has been compared with observations made on injured and imperfectly developed brains in man. The results have led to the conclusion that certain forms of the work of the cerebrum are localized and that some of its parts are concerned in processes that are different from those of others. In addition to this, the location upon the cerebral surface of the portions having to do with motion, vision, speech, and hearing have been rather accurately determined. Fig. 36. It must not be inferred from this, however, that all the activities of the cerebrum are localized. Furthermore, the function of much of the cerebrum is still unknown.

Nervous Control of Important Processes.

Circulation of the Blood. The ability to contract at regular intervals has been shown to reside within the heart itself. Among other proofs is that furnished by a cold-blooded animal, like the frog, whose heart remains active for quite a while after removal from its body. These automatic contractions, however, are not sufficient to meet all the demands made upon the circulation. The needs of the tissues for constituents of the blood vary with their activity and

it is therefore necessary to frequently vary the force and rapidity of the heart's contractions. Such changes the heart is of itself unable to bring about.

For the purpose of controlling the rate and force of the heart's contractions, it is connected with the central nervous system by two kinds of nerves: 1. Nerves containing fibers that convey excitant impulses to the heart to quicken its motion. 2. Nerves containing fibers that convey inhibitory impulses to the heart to slow its motion.

The cell-bodies of the excitant fibers are found in the sympathetic ganglia, but they are connected by fibers with the medulla, by which they are controlled. The cell-bodies of the inhibitory fibers are also in the medulla and they pass to the heart as a part of the spinal accessory and vagus nerves.

In addition to the fibers above mentioned, are those that convey impulses from the heart to the medulla. These act reflexively, when the heart is likely to be overstrained, to cause a dilation of the blood vessels which lessens the pressure that the heart must exert to empty itself of blood, and in this way serves as a kind of safety valve for the heart.

Changes in the rate and force of the heart's contractions can be made to correspond only to the general needs of the body. When the blood to a particular organ is to be increased or diminished, the muscle in the walls of the arteries must be called into play. The arterial muscle is controlled by fibers from sympathetic ganglia, which in turn are controlled by fibers from the medulla. The action of these muscles in varying the blood supply has already been considered. (P. 19.)

It is thus seen that the control of the circulation belongs to nerve centers in the medulla. These centers act reflexively and are stimulated by a number of conditions that relate to the movement of the blood through the body.

Respiration. The respiratory nerves connect the different muscles of respiration with a cluster of cell-bodies in the medulla, called the *respiratory center*. This together with the nerves and muscles in question, form a self-acting or automatic mechanism, similar in some respects to that of the heart. Through the impulses passing from the center to the respiratory muscles a rhythmic action is maintained sufficient to satisfy the usual needs of the body for oxygen. The demand for oxygen, however, varies with the activity of the body and to such variations the respiratory center alone is unable to respond. The regulating factor of the respiratory movements has been found to be the condition of the blood with reference to the presence of oxygen and carbon dioxide. If the blood contains much carbon dioxide and little oxygen it acts as a strong stimulus to the respiratory center, causing it, in turn, to stimulate the muscles with greater intensity and frequency. On the other hand, if the blood contain much oxygen and little carbon dioxide, it acts only as a mild stimulus. This explains how physical exercise may increase the force and rapidity of the respiratory acts. The muscles at work consume large quantities of oxygen and give much carbon dioxide to the blood. In this way they get the blood into such a condition that it can act strongly upon the respiratory center.

The respiratory center is also connected by nerves with the mucous membrane lining the air passages. Any irritation of the nerves in the membrane

is transmitted to the respiratory center and this leads to such modifications of the respiratory acts as sneezing and coughing.

There are also centers in the brain which modify the action of the respiratory center. This is shown by the fact that one can voluntarily change the rate and force of the respiratory acts.

Digestion of the Food. From the mucous membrane of the alimentary canal numerous fibers pass to the medulla. Fibers also pass from the medulla to the sympathetic nervous ganglia and to the muscles and glands concerned in digestion. Food in the canal, by its pressure against the walls, stimulates the fibers in the mucous membrane and these in turn act upon the nerve centers. These now stimulate, chiefly through the sympathetic cells, the muscles and glands of digestion. In this way the secretions of the various liquids and the movements of the canal occur with direct reference to the food present to be acted upon.

Hygiene of the Nervous System.

The peculiar work of the nervous system requires of it an extreme delicacy of structure. For this reason there is no tissue in the body so easily injured as the nervous tissue. This necessitates special provisions for protection from physical injuries, such as have already been noted. (P. 124.) There is no provision, however, for the protection of the nervous system from continued misuse, or direct abuse, on the part of the individual.

The far-reaching effect of nervous disorders is another reason for carefully regarding the conditions that make or mar the efficiency of the system. Because of its relation to different parts of the body, weakness of the nervous system is as frequently manifested through the inefficiency of different organs as through well recognized nervous symptoms. Poor digestion, irregularities of the heart's action, troubles with the eyes, etc., are quite frequently indicative of overtaxed nerves, and disappear when they regain their normal condition.

Mental work is conducive to the vigor of the nervous system. Even severe mental exertion may be undergone without bad effect, provided proper hygienic conditions are observed. But "brain workers" as a class are more or less liable to nervous derangements. For this reason they should observe at least the more general rules in caring for the nervous system and practice economy in the use of nervous energy.

Plenty of sleep is one of the first requirements of the nervous system. It is during sleep that the exhausted brain tissues are replenished. To shorten the time required for sleep is to weaken the brain and lessen its working force. No one should attempt to get along with less than eight hours of sleep each day and most people require more.

Fretting and worrying are unhealthful forms of nervous activity

and should, if possible, be avoided. Certainly the vast quantity of nervous energy which is expended in these ways cannot be used in useful work. A fretting person may be likened to a leaking steam engine. The escaping steam not only lessens the working power of the engine but is disagreeable and distracting as well. It should be remembered in this connection that worry and not work usually causes the mental wreck.

Physical Exercise properly taken is essential to the nervous system both for its direct and indirect effects. A large proportion of the nerve cells have for their function the production of motion and are called into play only through muscular activity. Physical exercise also counteracts the unpleasant effects of mental work. Hard study causes an excess of blood to be sent to the brain and a diminished amount to other parts of the body. Exercise redistributes the blood and equalizes the circulation. Light exercise, therefore, should follow hard study. The student before retiring at night is greatly assisted in getting to sleep and put in better condition for the next day's work, by fifteen or twenty minutes of light gymnastics.

The nervous system is also benefited through the general effect of physical exercise upon the organs of digestion, circulation, and respiration in causing them to provide a more liberal supply of food and oxygen to all the tissues of the body.

Nervousness. Through excess of mental work, long continued anxiety, disorders of the eyes, the use of much tea or coffee, or other causes, a weakened condition of the nervous system is frequently induced which is indicated chiefly by a supersensitiveness to all forms of stimuli. This condition, described by the general term, nervousness, is not only a source of great discomfort and annoyance but is wasteful of nervous energy and a menace to the general health.

The first step towards securing relief from such a condition should be the removal of the cause. At the same time there should be cultivated that condition of *mental poise* which enables one to resist many causes of irritation. Special exercises that have for their aim the equalization of the circulation or the strengthening of the blood vessels of the neck and the brain also have beneficial effects.

Nervousness in children often results from the work and worry of school life. Frequent examinations, the grading of class recitations, nagging on the part of the teacher, and other influences that keep children on a nervous strain are highly injurious, and to them may be attributed not a few of the nervous disorders of school days. Such

school work of course defeats the very aim for which it is intended and should be eliminated from all school system as soon as possible.

Effect of Drugs. Because of its delicacy of structure a number of chemical compounds, or drugs, are able to produce injurious effects upon the nervous system. Some of these are violent poisons while others, in small quantities, are mild in their action. Certain ones in addition to their direct physiological effect, bring about modifications in the nervous system which cause an unnatural appetite, or craving, that leads to their continued use. This is the case with alcohol,* the intoxicating substance in the usual saloon drinks, and with nicotine,† the stimulating drug in tobacco. The same is true of such drugs as morphine and chloral and several others that are frequently used as medicines. This danger of becoming a *slave* to a useless and pernicious habit should dissuade every one from the use of any and all drugs, except in cases of positive emergency.

The Power of Self-Control should be cultivated as much for its effect upon the nervous system as upon the "moral fiber." It is the chief safeguard against the formation of bad habits and the only means of redemption from such habits that have already been formed. Persistent cultivation of the power to control the appetites and the passions,

***The Injurious Effects of Alcohol** upon the body, which have been referred to at different times, may now be summarized. Alcohol injures protoplasm and leads to diseases of important organs, as the liver, kidneys, and stomach; it disturbs the nervous and muscular control of the circulation; it interferes with the action of the brain; it causes a general weakness of the entire body and diminishes its "power of resistance" to attacks of disease; and, besides, *creates* an appetite that is hard to control. While alcohol can be oxidized in small quantities in the tissues and, to a limited extent, can supply energy, the body has no way of storing it or of regulating its supply to the cells. Its use as a beverage is a dangerous practice. Its value as a medicine is a question upon which authorities do not agree.

†**Nicotine** is an oily, colorless liquid which may be extracted from the tobacco plant. Its action on the nervous system is that of a poison. Taken in small quantities it is a mild stimulant and, if the doses are repeated, a habit is formed which is difficult to break. Tobacco is used mainly for the stimulating effects of this drug. While not so serious in its results as the alcohol and morphine habits, the use of tobacco is of no benefit, is a continual and useless expense, and, in many instances, causes a derangement of the healthy action of the body. To the bad effects of the nicotine, may be added those of questionable substances added by the manufacturer, either for their agreeable flavor or for adulteration.

The use of tobacco by the young is especially injurious, as it interferes with the proper development of both body and mind. The *cigarette*, which has so many consumers among small boys, has done no end of harm and every effort should be made to prevent its use.

as well as all forms of activity that may injure the body or the higher nature, gives a power and tone to the nervous system that raises the individual to a higher plane of life. Moreover, it is the necessary condition for the exercise of *deliberate choice* in supplying the needs of the body.

Fainting, attended with or without loss of consciousness, is caused by an insufficient supply of blood to the brain. The usual remedy is to lay the patient on his back with the head slightly lower than the rest of the body and make provisions, if necessary, for fresh air. A little cold water may be dashed in the face and strong ammonia, or smelling salts, applied to the nostrils. The clothing should be loosened around the neck and chest and where the condition is prolonged, artificial respiration should be applied.

Summary. The nervous system is able to control and co-ordinate the different organs of the body through its intimate connection with all parts and through a stimulus (the nervous impulse) which it supplies and transmits. Nervous reactions, originating from the effects of external stimuli, follow definite paths and lead to activity of different parts of the body. All such reaction pathways are through the central nervous system. In voluntary action the reaction is through the cerebrum—a condition that leads to important modifications in the results. The cerebrum is the organ of the mind. The other divisions of the nervous system are so closely related that their special work can scarcely be separated from the general work of the nervous system.

Review Questions. 1. Give the function of each of the parts of the nerve cell or neurone.

2. Give the nature and purpose of the nervous impulse.

3. What arrangements are to be found for exciting impulses in the different nerve cells?

4. Describe a reflex action and show how it is brought about.

5. Distinguish between afferent, efferent, and intermediate cells.

6. State the purpose of the sympathetic cells.

7. How do reflex actions protect the body? In what sense are all of the actions of the body reflex?

8. How does voluntary action differ from reflex action?

9. How does automatic action lessen the work of the nervous system?

10. Why are habits hard to change? Show the importance of forming useful habits.

11. Discuss the relation of mental work, sleep, exercise, and the use of drugs to the vigor of the nervous system.

12. How does the cultivation of the power of self-control strengthen the nervous system?

CHAPTER XVIII.

PRODUCTION OF SENSATIONS.

Impulses of afferent nerve cells serve two purposes. They lead to motion in different parts of the body and they stimulate activity within the cerebrum. Cerebral activity is of different kinds, the most elementary being called *sensations*. The term is used here in a technical sense and sensations must not be confused with the nervous impulses on the one hand or with the secondary cerebral effects, called emotions, on the other. They are properly regarded as the immediate effects of afferent impulses on the brain and as the first stage in the series of mental processes that these impulses may arouse.

In some way not understood the brain is able to refer the sensation to the part of the body at which the impulses originate. Pain, for example, is felt not at the brain, where the sensation is produced, but at the injured part. This act of the brain is known "as localizing the sensation."

Classes of Sensations. Perhaps as many as twenty distinct sensations such as pain, touch, hunger, etc., are recognized. If these are studied with reference to their origin, it will be seen that part of them arise by the action of well defined stimuli upon special contrivances, known as the sense organs, while the others, as a rule, arise from indefinite stimuli upon parts of the body that do not possess sense organs. The first class, and this includes the sensations of touch, temperature, taste, muscular sensations, smell, hearing, and sight, are known as *special* sensations. The other class, which includes the sensations of pain, hunger, thirst, nausea, comfort, discomfort, and those due to disease, are known as *general* sensations.

Purpose of Sensations. Sensations indicate within the brain conditions that exist outside of it. By means of special sensations the physical conditions surrounding the body are made known and through the general sensations the brain is impressed with the state of the various organs within the body. In this way sensations provide the neces-

sary conditions for intelligent and purposeful action on the part of voluntary organs. Furthermore, since sensations supply the only basis for knowledge of any kind, the so-called "mental life" is entirely dependent upon them. Without sensation, there can be no thought.

The Steps in the Production of Sensations are not essentially different from those in the production of reflex action. First of all, external stimuli act on the fiber terminations in the sense organs, or elsewhere, starting nervous impulses in different cells which pass to some part of the central nervous system. The reaction then passes through the cells of the central system to the part of the cerebrum which gives rise to the sensation. Thus, the final response to the stimulus, instead of being the contraction of a muscle, or the secretion of a gland, is an activity of the cerebrum.

In the production of any special sensation the following parts are concerned:

1. A sense organ where the termination of the afferent cells is acted upon by the stimulus.
2. The part of the brain which gives rise to the sensation.
3. A chain of nerve cells which transmits the reaction from the sense organ to the brain.

Sense Organs may be regarded as special receivers of the nervous stimuli. Their purpose, in all instances, is to cause the stimulus to act to the best advantage on the terminations of the nerve cells with which they are in close connection. It may be inferred, therefore, that the construction of any sense organ will have special reference to the nature of the stimulus which it is to receive.

Simple Forms of Sense Organs. The simplest form of a sense organ is one found among various tissues. It consists of the terminal branches of a nerve fiber spread over a small area among the cells, as a network or plexus. Such endings are very numerous in the skin and muscles.

Next in order of complexity are the *end-bulbs*. These consist of rounded, or elongated, connective tissue capsules within which nerve fibers terminate. On the inside the fiber loses its sheath and divides into branches which wind around through the substance of the capsule. End-bulbs are abundant in the lining membrane of the eye, called the conjunctiva. They are also found in the skin of the lips and in the tissues around the joints.

Slightly more complex than the end-bulbs, are the *touch-corpuseles*,

the chief sense organs in the skin. They are elongated, bulb-like bodies, having a length of about one three-hundredth of an inch and are composed chiefly of connective tissue. Each corpuscle receives the termination of one or more nerve fibers. These, on entering, lose the medullary sheath and separate into a number of branches which penetrate the corpuscle in all directions. The touch corpuscles are found chiefly in the papillae of the dermis. Fig. 29.

Pacinian Corpuscles. These are the largest of the simple forms of sense organs and are easily seen with the naked eye. They lie along the course of nerves in many parts of the body and have the general form of grains of wheat. The Pacinian bodies are composed of connective tissue arranged in separate layers around a narrow central cavity, called the core, which contains the termination of a large nerve fiber. They are found in the connective tissue beneath the skin, along the tendons, around joints, and among the organs of the abdominal cavity.

Observation. Spread out the mesentery of a cat and hold it between the eye and the light. Pacinian corpuscles will be seen in the form of small translucent bodies. Secure a portion of the mesentery over a circular opening in a thin piece of cork and examine it with the microscope with a low power. Follow the course of the nerve fiber to the nerve from which it branches.

The simple forms of sense organs have a more or less general distribution over the body and are concerned in the production of three special sensations. These are touch, temperature, and the muscular sensation.

Touch, or feeling, is the simplest of the special sensations. The sense organs employed are the touch corpuscles and their stimulus is some form of pressure, or impact. Pressure applied to the skin, by acting on the fiber terminations within the corpuscles, starts the impulses which pass to the brain. It is found that *change of pressure*, rather than pressure that is constant, is the active stimulus. That sensations from different parts of the skin vary, is shown by the following

Experiment: Place the points of a pair of dividers on the back of the hand of one who looks in the opposite direction. Is one point felt or two? Repeat several times, changing the distance between the points, until it is fully determined how near together the points must be placed in order to be felt as one. In like manner test other parts of the body, as the tips of the fingers and the back of the neck. Compare the results obtained at different places.

Temperature Sensations are limited almost entirely to the skin. They are of two kinds which are designated as *heat* sensations and *cold* sensations. Whether the temperature sense organs are different in structure from the touch corpuscles is not known. It is known, however, that the same corpuscles do not respond alike to heat, cold, and pressure.

Experiment. Slowly and evenly draw a blunt pointed piece of metal over the back of the neck. If it be of the temperature of the skin, only touch sensations will be experienced. If it be a little colder (the temperature of the room) sensations of cold will be felt at certain spots. If slightly warmer than the body, heat sensation spots will be found on other parts of the skin. If the hot and cold sensation spots be marked and tested from day to day, they will be found to remain constant as to position.

A *change of temperature*, rather than any specific degree of heat or cold, is the active temperature stimulus. The sensation of warmth is obtained when the temperature of the skin is being raised, and of cold when the temperature of the skin is being lowered. Hence, sensations can indicate only in a relative way the actual temperature of objects.

Muscular Sensations refer to impressions which are produced by impulses arising at the muscles. These originate at the fiber terminations which are found in both the muscles and their tendons. By muscular sensations one is conscious of the location of a contracting muscle and of the degree of its tension. They also make it possible to judge of the weight of objects. There is doubt, however, of the accuracy of classifying these as special sensations.

The Sense of Taste. The sense organs of taste are found chiefly in the mucous membrane covering the upper surface of the tongue. If this surface be examined, a number of rounded elevations, or large papillae, will be found. Toward the back of the tongue two rows of these, larger than the others, converge to meet at an angle, where is located one of exceptional size. Surrounding each papilla is a narrow depression within which are found the sense organs of taste, called the *taste buds*. Each bud contains a central cavity which communicates with the surface by a small opening—the gustatory pore. Within the cavity are many slender spindle-shaped cells from which hair-like projections, at one end, extend toward the gustatory pore while they terminate, at the other end, in short fibers. Branches from the nerves of taste enter at the inner end of the taste bud and spread out

between the spindle-shaped cells. These find their way to the brain as parts of two pairs of cranial nerves: those from the front of the tongue joining the trigeminal nerve and those from the back of the tongue, the glossopharyngeal nerve.

The gustatory stimulus is some chemical or physical condition of substances which is manifested only when they are in a liquid state. For this reason only liquid substances can be tasted. Solids, to be tasted must first be dissolved.

The different taste sensations are described as bitter, sweet, sour, saline, and alkaline, and in the order named are recognized as the tastes of quinine, sugar, vinegar, salt, and soda. As to the manner in which these different tastes are produced, little is known. Flavors such as vanilla and lemon, and the flavors of meats and fruits are really smelled and not tasted.

The Sense of Smell. The sense organs of smell are found in the mucous membrane lining the upper divisions of the nasal cavities. Here are found two kinds of cells in great abundance—the columnar epithelial cells, and the cells which are recognized as the sense organs of smell. The latter are spindle-shaped, having at one end a slender thread-like projection which reaches the surface and, at the other end, a fiber which joins the olfactory nerve. In fact the olfactory cell resembles closely a nerve cell, and is thought to be a nerve cell by many authorities.

The divisions of the olfactory nerve pass through many openings in the ethmoid bone of the skull and connect with the olfactory lobes of the cerebrum.

The Olfactory Stimulus. Only substances in the gaseous state can be smelled. From this it is inferred that the stimulus is supplied by the movements of the gas particles. Solids and liquids are smelled by means of the gas particles which they exude. It is also necessary that the odoriferous substance be kept moving through the nostrils and that it come in contact with the olfactory cells.

Sight and Hearing. The sense organs of sight and hearing, which are highly complicated structures, are considered in the chapters following.

Summary. Sensations are activities of the cerebrum that have reference to conditions found either within the body or outside of it. They are excited by afferent impulses and are necessary for the intelli-

gent and purposeful action of the voluntary organs and for acquiring knowledge. General sensations indicate conditions of the various organs of the body while special sensations, as a rule, denote conditions external to the body. The sense organ is a device for enabling the stimulus to act to the best advantage on the afferent nerve cells in starting the impulses.

Review Questions. 1. Compare sensations and reflex actions with reference to their nature and cause.

2. How do general sensations differ from special sensations?

3. Of what value is pain in the protection of the body?

4. Of what value are the feelings of comfort and discomfort in the care of the body?

5. What different kinds of sense organs are found in the skin?

6. Through what sense avenues is one made aware of the presence of solids, liquids, and gases?

7. State the purpose of the sense of smell; of taste.

CHAPTER XIX.

THE LARYNX AND THE EAR.

General Facts Relating to Sound. If some sonorous body, as a bell be struck, it is given a quivering, or vibratory, motion which it imparts to the substances with which it comes in contact. These take up the movements and pass them to objects more remote, and they in turn give them to others, until a very considerable distance is reached. Such moving vibrations, or waves, constitute the external stimuli of the organ of hearing and are called *sound waves*. Sound waves always originate in vibrating bodies. Their usual mode of progress is through the air which, because of its lightness, elasticity, and abundance easily receives impressions from vibrating bodies and transmits them in all directions. While these movements are correctly classified as waves, they bear little resemblance to the familiar waves on water. Instead of being made up of crests and troughs they consist of alternately condensed and rarefied portions that have been caused by the backward and forward movements of the vibrating particles. They also pass through the substances that transmit them in all directions from the point of origin, instead of spreading like water waves over a surface. In the sound waves, as in all other waves, however, it is only the wave form that moves forward, the individual particles that make it up simply vibrating back and forth.

Any sound wave represents a small but definite amount of energy which is a part of the original force that acted on the vibrating substance. When they strike against bodies they are, therefore, able to exert a small amount of force which, under favorable circumstances, is capable of setting the bodies into vibration. It is because of this fact that sound waves may be employed as nervous stimuli.

Sound waves are transmitted by solids and liquids as well as by air. They may be re-enforced by suitable contrivances such as sounding boards and air columns. The *pitch* or height of a sound, depends upon the rapidity of the vibrations of the sonorous body. The inten-

sity or energy of a sound depends primarily upon the force applied to the sonorous body.

Simple Experiments. 1. *To illustrate the origin of sound.* (a) Strike a bell an easy blow and hold some light substance, such as a pith ball attached to a thread, against its side, noting result. (b) Sound a tuning fork by striking it against a table. Test it for vibrations as above. (c) Pluck a string of a guitar, or violin, and find proofs that it is vibrating while producing sound.

2. *To show transmission of sound.* Vibrate a tuning fork and press the stem against a table or desk. The vibrations will be perceived in all parts of the room. Now press the stem lengthwise against a small block of wood, and, after setting it in vibration, lower the block into a tumbler of water which is resting on the table. This sound will also reach to all parts of the room. Observe that to reach the ear the vibration from the fork must pass through a solid, a liquid, and the air.

3. *To show effects of sound waves.* While holding a thin piece of paper against a comb with the lips, produce musical tones with the vocal cords. The paper will be set into vibration by the sound waves, producing the so-called "comb music."

4. *Re-enforcement of sound.* (a) Vibrate a tuning fork in the air noting feebleness of tone produced. Then hold the stem against a door or the top of a table, noting the difference. (b) Hold a vibrating tuning fork over a tall jar or bottle and gradually add water. A depth will be reached when the air in the vessel re-enforces the sound.

The Value of Sound Waves from a physiological standpoint is not easily overestimated. They indicate the condition of one's surroundings, as regards rest or motion, and give warning of approaching danger. They comprise the chief means of communication between man and his fellows and, in the sphere of music, provide one of the most elevating forms of entertainment. The existence of two instruments of sound in the body—one for the production, the other for the detection of sound—is certainly suggestive and emphasizes the ability of the body to adapt itself to, and make use of, its physical environment. Both of these instruments are constructed with special reference to the nature and properties of sound waves.

The Larynx.

The Sound-Producing Mechanism of the body consists of the following parts:

1. Delicately arranged bodies which are easily set into vibration.
2. An arrangement for supplying the necessary force for making them vibrate.

3. Contrivances for modifying the vibrating parts so as to produce changes in pitch and intensity.

4. Parts which re-enforce the original vibrations.

5. Organs by means of which the sound waves are converted into the forms of articulate speech.

The central organ in this complex mechanism is the larynx.

The Larynx, which forms a part of the air passages (p. 31), is a short tube situated immediately above the trachea. Mucous membrane lines the inside and small muscles cover most of the outer surface. The framework is made up of cartilage. At the top it is partly encircled by a small bone (the hyoid), and its opening into the pharynx is guarded by a flexible lid, called the epiglottis. While the cartilage in the walls is in eight separate pieces, the greater portion of the structure is formed by two pieces only—the thyroid cartilage and the cricoid cartilage. Both of these can be felt in the throat—the former as the projection known as “Adam’s apple,” and the latter as a broad ring a little below.

The thyroid cartilage consists of two V-shaped pieces, one on either side of the larynx, meeting at their points in front and each terminating at the back in an upward and a downward projection. Between the back parts of the thyroid is left a space which is occupied chiefly by the larger portion of the *cricoid cartilage*. The latter has the shape of a signet ring, and is so placed that the part corresponding to the signet fits into the thyroid space while the ring portion encircles the larynx below the thyroid. Muscles and connective tissue pass from one cartilage to the other at all places save one, on each side, where the downward projections of the thyroid form hinge-joints with the cricoid. This joint permits of the motion of either cartilage upon the other.

At the top of the cricoid on each side is a small triangular piece, called the *arytenoid cartilage*. Each arytenoid is movable on the cricoid and is connected with one end of a vocal cord.

The Vocal Cords consist of two narrow strips of tissue which, connecting with the thyroid cartilage in front and the arytenoid cartilages behind, lie in folds of the mucous membrane. Above the vocal cords, and resembling them in appearance, are two other folds of the membrane called the false vocal cords. The open space between the “true” cords is called the *glottis*. When sound waves are not being produced the glottis has a triangular form due to the spreading apart of the arytenoid cartilages and their attached cords. But

when in use the cords are made to approach each other until the glottis is only a narrow slit.

The Location of the Larynx, in the air passage, enables the expiratory muscles to be used as *accessory organs* in the production of the voice. By the force which they are able to give to the air passing from the lungs, the cords are set into vibration. During the production of vibrations the natural expulsion of the air is checked by the partial closing of the glottis and it is held back in the lungs. It is then forcibly expelled against the cords.

To Produce the Voice a special set of muscles draws the arytenoid cartilages toward each other, bringing their margins very near and parallel to each other. In this position they are easily set into vibration by blasts of air from the lungs. *Changes in pitch* are caused by varying the tension of the cords. This is accomplished by tilting the thyroid cartilage in such a way that the upper portion moves away from the arytenoids. These changes are indicated by movements of the larynx and may be easily observed if the finger is pressed against it, between the thyroid and the cricoid cartilages, while the musical scale is being sung. The distance between them diminishes in ascending the scale and increases in descending the scale.

In the production of tones of very high pitch, the vibrating portion of the cords is thought to be actually shortened by the margins being drawn into contact at the back.

The intensity of the voice is governed by the force with which the air is expelled from the lungs. The vibrations of the cords are also greatly re-enforced by virtue of the peculiar structure of the upper air passages, which act as resonance tubes.

In the production of speech the mouth is recognized as the chief organ in modifying the vibrations of the vocal cords. Its movements during speech are quite significant and may be studied with profit. The "vowels" are more nearly the pure vibrations of the cords while the "consonants" are largely modifications produced by the tongue, teeth, and lips. Ordinarily speech is carried on without change in pitch. In whispering the vocal cords do not vibrate.

Observations. 1. Lightly grasp the larynx with the fingers while talking. Observe the changes both in the position and shape of the larynx in the production of different sounds.

2. Observe the difference in the action of the muscles of respiration in the production of loud and faint sounds.

3. Pronounce slowly the vowels, A, E, I, O, U, and the consonants, C, F, K, M, R, S, T, and V, noting the shape of the mouth, the position of the tongue, and the action of the lips in each case.

The Ear.

The Sense Organ of Hearing is a contrivance for enabling sound waves to act as sensory stimuli. In the performance of its function it receives, transmits, and concentrates the waves on a suitable exposure of nerve cells. It includes three parts—the external ear, the middle ear, and the internal ear.

The External Ear consists of the part on the outside of the head called the *pinna*, or auricle, and the tube leading into the middle ear called the *auditory canal*. The pinna by its peculiar shape aids to some extent the entrance of sound into the canal. The auditory canal is a little more than an inch in length and one-fourth of an inch in diameter and is closed at its inner end by a thin membrane, called

The Membrana Tympani. This membrane consists of three thin layers. The outer layer is a continuation of the lining of the auditory canal; the inner, is a part of the membrane of the middle ear;

while the middle is a layer of connective tissue. Being thin and delicately poised, the membrana tympani is easily made to vibrate by the sound waves which enter the auditory canal.

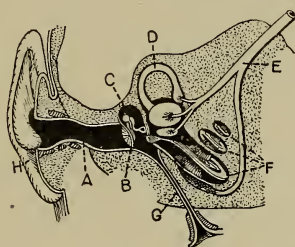


Fig. 37. Diagram of the organ of hearing. A. Auditory canal. B. Membrana tympani. C. Middle ear with a chain of bones. D. Semi-circular canal. E. Auditory nerve. F. Cochlea. G. Eustachian tube. (Reduced from Rettger's Advanced Lessons in Physiology.)

The Middle Ear, or tympanum, is an irregular cavity in the temporal bone, lined with mucous membrane and connected with the pharynx by a slender canal known as the *eustachian tube*. It is also filled with air. Extending

across the middle ear and connecting with the membrana tympani, on one side, and with a membrane closing a small passage to the internal ear, on the other, is a chain of three small bones. These

named in their order from the membrane are, the *malleus*, the *incus*, and the *stapes*. Where the malleus joins the membrane is a small muscle whose contraction has the effect of tightening the membrane. The eustachian tube admits air freely to the middle ear, providing in this way for an equality of atmospheric pressure on the two sides of the membrane. The chain of bones transmits vibrations from the *membrana tympani* to the internal ear.

In the transmission of vibrations across the middle ear an actual concentration of wave force occurs in the following manner: 1. The chain of bones, being attached to the walls of the middle ear, forms a lever of the second class in which the malleus is the long arm and the incus and the stapes, the short arm, their ratio being about that of three to two. 2. The area of the *membrana tympani* is about twenty times as great as that of the internal ear which is acted upon by the stapes.

From this arrangement it follows that the force exerted by the stapes where it joins the internal ear is thirty times as great as that exerted on each corresponding area of the *membrana tympani*. In other words this arrangement enables the force of a sound wave upon a relatively large surface to be concentrated upon a surface which is relatively small.

The Internal Ear, or labyrinth, occupies a series of irregular canals in the petrous process of the temporal bone of the skull. (P. 99.) It is very complicated in structure but at the same time, very small. Its greatest length is about three-fourths of an inch and its greatest diameter not more than one-half inch. It consists of three main parts—the vestibule, the semi-circular canals, and the cochlea. It is double throughout, being made up of an outer portion which lies next to the bone and completely surrounds an inner portion of the same general form. The outer portion is surrounded by a membrane which serves as periosteum to the bone and, at the same time, holds the liquid belonging to this part, called the perilymph. The inner portion called the *membranous labyrinth*, consists essentially of a closed membranous sac filled with a liquid, called the endolymph, and contains the terminations of the auditory nerve.

The Vestibule is the central portion of the internal ear and is somewhat oval in shape. It is in communication with the middle ear through a small opening in the bone called the *fenestra ovalis*, at which place the stapes is in contact with its outer membrane. Six different

openings lead off from the vestibule at different places. The largest of these forms the main canal of the cochlea. The other five form the different openings into

The Semi-Circular Canals. These canals, three in number, pass through the bone in three different planes. One extends in a horizontal direction and the other two vertically, but each lies at right angles to the other two. Both ends of each canal connect with the vestibule, though two of them join by a common opening. The inner membranous labyrinth is continuous through each canal and is held in position by small strips of connective tissue.

The Cochlea is the part of the internal ear directly concerned in hearing. It consists of a coiled tube which makes two and one-half turns around a central axis and bears a close resemblance to a snail shell. It differs from a snail shell, however, in being made up of three separate canals, lying side by side. These are named the *scala vestibula*, the *scala tympani*, and the *scala media*. Any vertical section of the cochlea will show all three of these divisions. (Fig. 37.)

The Scala Vestibula and the Scala Tympani appear in cross section as the larger of the cochlear canals. The former, so named from its connection with the vestibule, occupies the upper position in all parts of the coil. The latter lies below at all places and is separated from the channels above partly by a margin of bone and partly by a membrane. It receives its name from its connection with the middle ear or tympanum. Both the *scala vestibula* and the *scala tympani* belong to the outer portion of the internal ear and are filled with the perilymph. At their upper ends they communicate with each other by a small opening.

The Scala Media lies between the *scala vestibula* and the *scala tympani* and is separated from each by a membrane. It is a part of the membranous portion of the labyrinth and is filled with the endolymph. It receives the terminations of fibers from the auditory nerve and may be regarded as the true sense organ of hearing. The nerve fibers terminate upon the membrane which separates it from the *scala tympani*, called the *basilar membrane*. This extends the length of the cochlear canal and is stretched between a projecting margin of bone on one side and the outer wall of the cochlea on the other. It is covered with a layer of well-formed cells, some of which have small, hair-like projections and are known as the *hair-cells*. Above the membrane and resting partly upon it, are two rows of rod-like bodies, called

the *rods of Corti*. These, by leaning toward each other, form a kind of tunnel beneath. They number more than 6,000 and form a continuous series along the margin of the membrane.

How We Hear. The sound waves which originate in vibrating bodies are transmitted by the air to the external ear. The pinna and

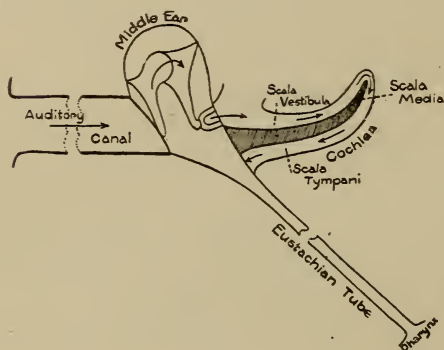


Fig. 38. Path of the sound wave through the ear. (Diagrammatic.)

This serves as stimulus to the fibers of the auditory nerve which transmits the impulses that cause the *sensation* of hearing to the brain.

Fig. 38. Much of the peculiar structure of the cochlea is not understood. Its minute size and its location in the temporal bone make its study extremely difficult. The connection of the scala tympani with the middle ear is supposed to furnish an outlet for the vibrations, thereby preventing echoes. The rods of Corti are thought to act as dampers on the basilar membrane, to prevent the continuance of vibrations when once they are started.

Theories of Hearing. The basilar membrane, while continuous throughout, may be regarded as made up of many separate cords of different lengths stretched side by side. Any given tone is able to set into vibration only those cords which sustain a fixed relation to the wave length in question. Thus, a tone of one pitch sets one portion of the membrane into vibration and has no effect on the other parts. This theory, which is based upon our knowledge of sympathetic vibration, was proposed by Helmholtz.

Another theory is that the entire basilar membrane responds to all vibrations and that the analyses of sound takes place in the brain.

A third view is that the filaments from the hair cells, rather than the basilar membrane, respond to the vibrations and stimulate the terminal branches of the nerve cells. This view* is based on a comparative study of the development of the so-called hair cells in a large number of the lower animal forms.

The Purpose of the Semi-Circular Canals is not understood. There is, however, much evidence for the belief that they act as sensory organs for balancing the body. Their removal or injury does not affect the hearing but does interfere with the ability to keep the body in an erect position.

Care of the Ear. The ear, being a delicate organ, is frequently injured by careless or rough treatment. The removal of ear wax by the insertion of pointed instruments has been found to interfere with the natural method of discharge and to irritate the membrane. It should never be practiced. It is unnecessary in the normal ear to cleanse the auditory canal proper, as the wax is passed to the end of the canal, by a natural process, where it is easily removed. If the natural process is obstructed, clean warm water and a soft linen cloth may be employed in cleaning the canal without liability of injury. Clean warm water may also be introduced into the ear as a harmless remedy in relieving inflammation of the auditory canal and the middle ear. Children's ears are easily injured through rough handling and it goes without saying that their ears should never be boxed or pulled.

It sometimes happens that a plug of wax gets lodged in the ear and closes the canal so completely as to cause temporary deafness. Such plugs are easily removed and the hearing restored by the physician and, both in the case of painful disturbances and in the gradual loss of hearing, he should be consulted.

Summary. Through the larynx and the ear, sound waves are utilized by the body in different ways but chiefly as a means of communication. The larynx produces sound on the principle of a reed instrument which is re-enforced and modified by the air passages. The ear supplies suitable conditions for the action of sound waves upon nerve cells. Both are constructed with special reference to the nature and properties of sound waves and illustrate the body's ability to adapt itself to, and make use of, its physical environment.

*Investigations by Ayers on "The Vertebrate Ear."

Review Questions. 1. Describe a sound wave. How does it originate? How is it transmitted? State its effect on delicately poised bodies?

2. How do sound waves differ from the waves on the surface of water?

3. How may sound waves be re-enforced?

4. Describe the plan for the production of sound waves in the body.

5. Account for the variations of pitch and intensity in sounds produced by the organ of the voice.

6. How is the sound produced by the vocal cords changed into speech?

7. What parts of the organ of hearing are concerned in transmitting sound waves?

8. Give purpose of the middle ear.

9. Trace a sound vibration from a bell to the basilar membrane and the impulses it causes from there to the brain.

10. Describe the membranous labyrinth.

11. Give directions for the proper care of the ear.

CHAPTER XX.

THE EYE.

Light Waves. The stimulus for the sensation of sight, called light, is supposed to consist of vibratory movements, or waves, of various lengths. These differ from sound waves in form, velocity, origin, and method of transmission. Light waves are able to pass through a vacuum showing that they are not dependent on the different forms of matter for transmission. They are supposed to be transmitted by what the physicist calls ether, a highly elastic and exceedingly thin substance which fills all space and penetrates all matter. As a rule light waves originate in bodies that are highly heated, being started by the vibrations of the minute particles of matter, called molecules.

The path of a light wave is determined by various conditions. Within a medium of uniform density it is transmitted in a straight line and with unchanging velocity. If it enters a rarer medium, its velocity increases: if a denser medium its velocity diminishes; and if it enters any of these media from any direction except perpendicularly, it is turned in its course, or *refracted*. If it strikes against some body lying in its course, it may be thrown off (*reflected*), or it may enter the body and be either *transmitted* through it or *absorbed*. In the latter case the force is spent in raising the temperature of the object.

Waves of light striking against the smooth surface of a mirror are thrown off in definite directions, depending on the angle at which they strike the mirror. (Illustrate by holding a mirror in the direct rays of the sun.) But light waves which strike rough surfaces are reflected in all directions and apparently without reference to the angle at which they strike. (Illustrate by placing a piece of white paper in the direct rays of the sun. It matters not from what direction it is viewed, intense rays of light from it strike the eye.) This kind of reflection, known as *diffusion*, plays a very important role in

rendering objects visible. Light from the sun, for example, when it strikes different objects on the earth is reflected from them in all directions. These reflected waves enable objects to act as independent sources of light and to become visible.

Formation of Images. Images are produced by light waves when they represent to the eye the form of the object from which they come. If, for example, a convex lens is moved backward and forward between a candle and a screen in a poorly lighted room, a position will be discovered where the form of the candle falls on the screen. This picture of the candle is called its image.

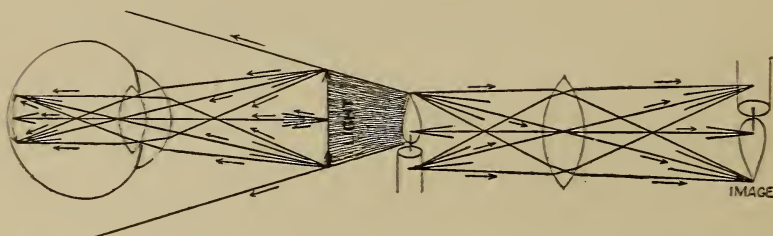


Fig. 39. Formation of images. On the right by a simple convex lens. On the left by the eye. The candle flame represents a luminous, or light-giving, body, while light passes from the arrow by reflection.

The explanation is as follows: The light of the candle comes from great numbers of separate and independent points in the flame. The lens, by its peculiar shape, refracts the separate waves so that those coming from any given point in the candle are brought to a corresponding point on the screen. Furthermore, the images of points on the screen occupy relations to each other similar to those in the candle. Thus the area of light on the screen has the form of the candle flame and may be called its image. The same explanation applies if, instead of the luminous candle, a body that simply reflects light, as a book, is used.

In figure 39, trace the different light waves from their points of origin, at the candle or arrow, to their points of convergence on the screen or retina. Account for the fact that the images are inverted.

Experiments Illustrating the Simple Properties of Light. 1. Heat an iron or platinum wire in a clear gas flame. Observe that when a high temperature is reached it gives out light or becomes luminous.

2. Cover one hand with a white and the other with a black piece of cloth

and hold both for a short time in the direct rays of the sun. Note and account for the difference in temperature which is felt.

3. Stand a book, or a block of wood, by the side of an empty pan in the sunlight, so that the end of the shadow falls on the bottom of the pan. Mark the place where the shadow terminates and fill the pan with water. Account for the shadow's changing in length.

4. Place a coin in the center of an empty pan and let the members of the class stand where the coin is barely out of sight over the edges of the pan. Fill the pan with water and account for the coin's coming into view.

5. Hold a piece of cardboard, about eight inches square and having in the center a smooth, round hole an eighth of an inch in diameter, in front of a lighted candle in a darkened room. Back of the opening place a muslin or paper screen. Look for an image of the candle on the screen. Account for the fact that it is inverted. Hold a convex lens between the cardboard and the screen so that the light passes through it also. The image should now appear smaller and more distinct.

The Sense Organs of Sight consist of the two eyeballs and their accessory parts. Each is located within a cavity of the skull bones, called the *orbit*, where it is held in position by suitable tissues and turned in different directions by a special set of muscles. A cup-like receptacle is provided within the orbit by layers of fat and a smooth surface is supplied by a double membrane that lies between the fat and the eyeball. In front the eyeballs are protected by movable coverings, called the eyelids. These are composed of dense layers of connective tissue, covered on the outside by the skin and lined within by a sensitive membrane, called the *conjunctiva*. At the base of the lids the conjunctiva passes to the eyeball and forms a firmly attached covering over its front surface. It prevents the passage of foreign materials back of the eyeball and by its sensitiveness stimulates effort for the removal of irritating substances from beneath the lids.

The Eyeball, or globe of the eye, is a contrivance for properly directing and focusing light waves upon a sensitized nervous surface which it incloses and protects. In shape it is nearly spherical, being about an inch in diameter from right to left and nine-tenths of an inch both in its vertical diameter and from front to back. It has the appearance of being formed by the union of two spherical segments of different sizes. The smaller segment which forms about one-sixth of the whole, is set upon the larger and forms the projecting transparent portion in front. The walls of the eyeballs are made up

of three separate layers or coats—an outer, a middle, and an inner coat—while the interior consists of liquid and solid portions.

The Outer Coat surrounds the entire globe of the eye and consists of two parts—the sclerotic coat and the cornea. The *sclerotic*

coat covers the greater portion of the larger spherical segment and is recognized in front as the “white of the eye.” It is composed mainly of fibrous connective tissue and is dense, opaque, and tough. It preserves the form of the eyeball and protects the portions within. It is pierced at the back by a small opening which admits the optic nerve and in the front by a large opening which receives the cornea. The *cornea* forms the transparent covering over the lesser spherical segment of the eyeball and fits into a groove in the sclerotic coat like a watch-glass into its case. It

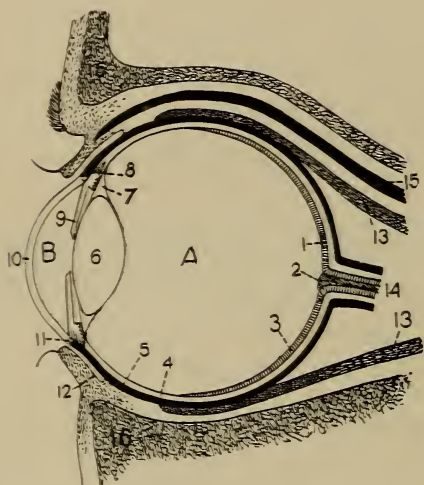


Fig. 40. Diagram of the eyeball in position. 1. Yellow spot. 2. Blind spot. 3. Retina. 4. Choroid coat. 5. Sclerotic coat. 6. Crystalline lens. 7. Suspensory ligament. 8. Ciliary processes and ciliary muscle. 9. Iris containing the pupil. 10. Cornea. 11. Lymph duct. 12. Conjunctiva. 13. Inferior and superior recti muscles. 14. Optic nerve. 15. Elevator of the eyelid. 16. Bone. A. Posterior chamber. B. Anterior chamber.

has a complex structure, consisting in the main of a transparent form of connective tissue, and serves the purpose of admitting light into the eyeball.

The Middle Coat consists of three connected portions—the choroid coat, the ciliary process, and the iris—which together surround the larger spherical segment. They are all highly vascular and contain the blood supply for the greater portion of the eyeball.

The choroid coat lies immediately beneath the sclerotic coat at all places except a small margin toward the front of the eye. It is composed chiefly of blood vessels and a delicate form of connective tissue that holds them together. It contains numerous pigment cells

(Fig. 2) which give the choroid a dark appearance and serve to absorb surplus light. Near the junction of the sclerotic coat and the cornea, the choroid separates from the outer wall and forms, by a number of folds, a slight projection into the interior space. These are called the ciliary processes. The effect of the folds is to collect a large number of capillaries into a small space and to give this part of the eyeball an extra supply of blood. Between the ciliary processes and the sclerotic coat is a small muscle containing both circular and longitudinal fibers, called the ciliary muscle.

The iris is a continuation of the choroid coat across the front of the eyeball. It forms a dividing curtain between the two spherical segments and is the part which gives the color to the eye. At its center is a circular opening called the *pupil* which admits light into the back part of the eyeball. By means of two sets of muscle fibers in the iris, it is able, by varying the size of the pupil, to regulate the quantity of light that enters. One set forms a thin muscular band which encircles the pupil and serves as a sphincter to close the opening. Opposing this are radiating fibers which pass from the pupil to the outer margin of the iris. Both muscles act reflexively and are stimulated by variations in the light falling upon the retina.

The Inner Coat, or Retina, is a delicate membrane containing the expanded portion of the optic nerve. It rests upon the choroid coat and spreads over about two-thirds of the posterior surface of the eyeball. Although not more than one-fiftieth of an inch in thickness, it presents a very complex structure, essentially nervous, and is made up of several distinct layers. Of chief importance is the layer of cells which are acted upon directly by the light and are named from their shape, the rods and cones. In contact with these, but occupying a separate layer, are the ends of small afferent nerve cells which communicate at the opposite ends with another layer of nerve cells from which fibers pass to form the optic nerve.

In the center of the retina is a slight depression which has a faint yellowish color and is called the *yellow spot*. This is the part of the retina most sensitive to light. Directly over the point of entrance of the optic nerve is a small area from which the rods and cones are absent and which, therefore, is not sensitive to light. This is called the *blind spot*.

Experiments. 1. Place a clear but rather concentrated solution of chrome alum in a glass vessel with flat sides and hold it between the eye and

the light from a window. If the eye be closed for a short time before looking at the solution, a round, rose-colored spot will be temporarily seen. This effect is due to the absorption by the yellow spot of certain light rays that pass through the solution.

2. The presence of the blind spot may be proven as follows: Close the left eye and with the right gaze steadily at the spot on the left side of this page. Then starting with the book a foot or more from the face, move it slowly



toward the eye. A place will be found where the spot on the right entirely disappears. On bringing it nearer, however, it is again seen. As the book is moved forward or backward, the position of the image of this spot on the retina changes. When the spot can not be seen, its image falls on the blind spot.

The Crystalline Lens. Immediately behind the iris and touching its posterior surface is a transparent, rounded body, called the crystalline lens. It is about one-fourth of an inch thick and one-third of an inch through its long diameter and is more curved on its posterior than on its anterior surface. It is inclosed in a membranous capsule, the edges of which connect with an extension of the choroid coat, called the *suspensory ligament*. Both the lens and the capsule are highly elastic.

The lens, together with the suspensory ligament and the ciliary processes, form a partition across the eyeball. This divides the eye space into two separate compartments which are filled with the so-called humors of the eye. The front cavity of the eyeball, which is subdivided into an anterior and a posterior chamber by the iris, is filled with the *aqueous* humor. This is a clear, watery, lymph-like liquid which contains an occasional white corpuscle. It has a feeble motion and is slowly but continuously added to and withdrawn from the eye. It is supplied mainly by the blood vessels of the ciliary processes and finds a place of exit through a small lymph duct at the edge of the cornea. (Fig. 40.)

The back part of the eyeball is filled with a soft jelly-like substance, called the *vitreous* humor. It is in contact with the surface

of the retina and the attachments of the lens, being separated only by a thin covering of its own, called the *hyaloid membrane*.

Both the aqueous and vitreous humors act as refractive media and aid in keeping the eyeball in shape.

Dissection of the Eyeball. Procure from the butcher two or more eyeballs obtained from cattle. After separating the fat, connective tissue, and muscles, place in a shallow vessel and cover with water. Insert a blade of a pair of sharp scissors at the junction of the cornea with the sclerotic coat and cut from this point nearly around the entire circumference of the eyeball, passing near the optic nerve. Spread open the parts in the water and identify the different structures from the descriptions in the text.

Open the second eyeball by simply removing the cornea and examine the parts in front of the lens.

How We See. To see an object four things must happen: 1. Light waves from the object must enter the eyeball. 2. These through the formation of an image are made to stimulate a portion of the retina which corresponds in form to that of the object. 3. Nervous impulses, started at the retina, pass to the visual area of the cerebrum. 4. This becoming active, gives rise to the sensation of sight.

Focusing Power of the Eyeball. From the cornea in front to the surface of the retina at the back of the eyeball, is a continuous series of transparent, refractive media. Name them. At two places, bodies corresponding to lenses are found. One of these is the cornea with its inclosed fluid; the other is the crystalline lens. These lenses cause light waves from objects to form images on the retina, for the same reason that the glass lens forms the image of the candle on the screen. Fig. 39. The iris, in addition to regulating the quantity of light, also causes it to fall in the center of the crystalline lens, the part that focuses most accurately. With the exception of the cornea the eyeball closely resembles a photographer's camera and is comparable to it, part for part. Its general structure and action may be imitated in the following manner:

In the center of one end of a crayon box, having a tight fitting lid, cut a hole half an inch in diameter. Fasten over this a small tin plate which has in its center a smooth, round hole less than one-fourth of an inch in diameter. Back of the hole fasten by a suitable support a convex lens. At the upper left hand corner of the box, cut another opening, one-fourth of an inch in diameter. Now fit a stiff piece of white paper in the back end of the box, so arranged that its position may be shifted.

If the lid be placed on the box and the opening in the center turned toward a window, an inverted image will be seen on the screen by looking in the hole at the corner of the box. Care must be taken that the head does not obstruct the light which passes from the window to the hole.

Because of the difference in density between air and the aqueous humor, the greatest degree of refraction occurs at the surface of the cornea.

Accommodation. A difficulty in focusing arises from the fact that the angle of divergence of light waves entering the eye from objects varies with their distance. Since the waves from any given point on an object pass in straight lines in all directions, waves entering the eye from distant objects are more nearly parallel than those from near objects. To adjust the eye to different distances, requires some change in the refracting parts that correspond to the degree of divergence of the light. This is accomplished by the crystalline lens through changes in its curvature.

When the divergence increases, as it does on looking from distant to near objects, the lens becomes more convex. When the divergence of the light diminishes, as in changing to distant vision, the lens becomes flatter and thinner. This changing of the lens to focus light from different distances, is called accommodation.

The method employed to change the shape of the lens is difficult to determine and different theories have been advanced. The following, proposed by Helmholtz, is the one most generally accepted:

The lens is suspended back of the pupil by its membranous capsule and the suspensory ligament. The suspensory ligament is attached to the sides of the eyeball in such a manner that it exerts continuous tension on the membranous capsule which, in its turn, exerts pressure on the sides of the lens, tending to flatten it.

This arrangement brings the elastic force of the eyeball into opposition with the elastic force of the lens. The ciliary muscle plays between the two in the following manner:

To thicken the lens, the ciliary muscle contracts, pulling forward the suspensory ligament and releasing its tension on the membranous capsule. This permits the lens to thicken by virtue of its own elastic force. *To flatten the lens* the ciliary muscle relaxes, the elastic force of the eyeball resumes the tension on the suspensory ligament and the membranous capsule resumes its pressure against the sides of the lens. This pressure, acting against the elastic force of the lens, flattens it.

In other words, when the ciliary muscle is relaxed, the lens is in the condition of a rubber ball with a weight upon it. By contracting, the muscle removes this pressure and permits it to assume its natural shape which is one of greater convexity than the one in which it is held.

Movements of the Eyeball as a whole are brought about by the action of six small muscles. Four of these, named from their positions the superior, inferior, internal, and external recti muscles, are attached at one end to the sides of the eyeball and at the other to the back of the orbit. These in the order named are able to turn the eyes upward, downward, inward, and outward. The other two, the *superior* and *inferior oblique* muscles, supplement certain movements of the recti muscles and, in addition, serve to rotate the eye. The movements of the eyeball are similar to those of a ball and socket joint. (Fig. 41.)

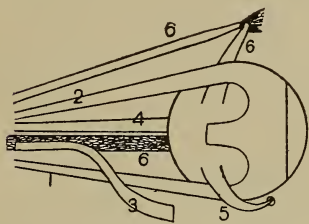


Fig. 41. Muscles of the right eyeball. 1, 2, 3, 4. The inferior, superior, external, and internal recti muscles. 5, 6. Inferior and superior oblique muscles.

Visual Sensations include sensations of color and what is called a general sensibility to light. Proof of the existence of these types of sensation is found in color blindness, a defect which renders the individual unable to distinguish color when he is still able to distinguish objects. Color sensations are the results of light waves of *different lengths* acting on the retina. While the method by which waves of one length produce one kind of sensation and those of another length a different sensation, is not understood, it seems quite possible that the cones are the portions of the retina acted upon to produce the color. On the other hand the rods are sensitive to all wave lengths and give rise to general light sensations. Many of the sight impressions are not sensations at all, but are to be classed as

Visual Inferences. "Seeing" is very largely the mental interpretation of the primary sensations described above and the conditions under which they occur. For example, our ability to see objects in their natural position when their images are inverted on the retina is explained by the fact that we are not conscious of the retinal image but of the mind's interpretation of it through experience.

Experience has also taught us to locate objects in the direction toward which it is necessary to turn the eyes in order to see them. In other words we see objects in the direction from which the light enters the eyes. That the object is not always in that direction is shown by the image in a mirror. The size and

form of objects are inferences based largely upon the size and form of the area of the retina which is stimulated. We judge of distance by the effort required to converge both eyes on the same object, by the amount of divergence of the waves entering the pupil, and also by the apparent size of the object.

Binocular Vision. In addition to directing the eyeballs so that light waves from any given object may enter them to the best advantage the muscles also enable the two eyes to be used as one. When the eyes are directed toward an object an image is formed on the retina of each and double vision is prevented only by the images falling on corresponding retinal areas. In each act of seeing, it becomes the task of the superior and inferior recti muscles to keep the eyes in the same plane and that of the internal and external recti muscles to produce the requisite amount of convergence. If slight pressure is exerted against one of the eyes this action of the muscles is prevented and objects are seen double. The advantages of two eyes over one in seeing, lie in the greater distinctness and broader range of vision and in the greater correctness of judgments of distance.

The Lachrymal Apparatus. Some of the methods of protecting the eyeball were indicated in the description of the cavity in which it is placed. It is further protected by the continual wetting of its front surface by a liquid secreted for this purpose, called *tears*.

The lachrymal glands are situated at the upper and outer margins of the orbits. They have the general structure of salivary glands and discharge their liquids by small ducts beneath the upper lids. From here the tears spread over the surface of the eyeballs and find their way in each eye to two small canals whose openings may be seen on the edges of the lids near the inner corner. These canals unite to form the *nasal duct* which conveys the tears to the nasal cavity on the same side of the nose. Fig. 42.



Fig. 42. Scheme for supplying moisture to the front of the eyeball. 1. Lachrymal gland. 2. Position of eyeball. 3. Nasal duct.

When by evaporation the eyeball becomes too dry, the lids close reflexively and spread a fresh layer of liquid over the surface.

Visual Defects. The delicacy and complexity of the sense organs of sight, render them liable to a variety of defects. An eye in a normal condition is able, when relaxed, to focus light from objects which are twenty feet or more away and is able to accommodate itself to objects as near as five inches. An eye is said to be *myopic* or *short-sighted* when it is unable to focus light waves from distant objects. In such an eye the ball is too long for the converging power of the lenses and the image falls in front of the retina. A *long-sighted* or *hyper-*

metropic eye is one which can focus waves from *distant* objects but not those from *near* objects. In such an eye the ball is too short for its converging power and the image of the object if formed would fall behind the retina. These defects in focusing are remedied by wearing spectacles whose lenses are shaped so as to counteract them. Short-sightedness is corrected by means of a concave lens and long-sightedness by a convex lens.

In *astigmatism* the parts of the eye fail to form an image in the same plane. As a result one part of the object will be seen distinctly while the other is dim or blurred. The cause lies in some defect in the curvature either of the cornea or crystalline lens. It is remedied by lenses ground to correct the particular defects which are present in a given eye.

Whenever defects in focusing are present, particularly in astigmatism, extra work is thrown on the muscles which move the eyeballs. The result is frequently to produce a condition known as "*muscle weakness*" which renders it both difficult and painful to use the eyes. Even after the defect in focusing has been remedied, the muscles recover slowly and must be used with great care.

Care of the Eyes. If proper care is exercised in the use of the eyes many of the common ailments and defects may be avoided. Anyone, whether his eyes are weak or strong, will do well to observe the following precautions:

1. Never read when the light is very intense or very dim.
2. When the eyes hurt quit using them.
3. Never hold a book so that the smooth page reflects light into the eyes. The best way is to sit or stand so that the light passes over the shoulder to the book.
4. Never study by a lamp that is not shaded.

If the eyes are weak use them less and wash them frequently in warm water or water containing enough salt to smart them slightly. When anything serious affects the eyes consult either an oculist, or a physician who has made a special study of the eye.

Students in the laboratory frequently, through accident, get strong chemicals, as acids and bases, in the eyes. The first thing to do in such cases is to flood the eyes with water. Any of the chemical remaining may then be counteracted with the proper reagent, care being taken to use a very dilute solution. For an acid use sodium bicarbonate (cooking soda) and for a base use a dilute solution of acetic acid (vinegar). To guard against getting the counteractive agent too strong for the inflamed eye, it may first be tried on an eye that has not been injured.

The eyes of school children often have defects, unknown to themselves or their parents, which render close work burdensome and cause pain in the eyes, headache, and general nervousness. The precaution

adopted by many schools, of examining the eyes of all the children with a view to detecting defects and causing them to be remedied, is most excellent and worthy of imitation.

Summary. Sight, the most important of the sensations, is accomplished through the action of light waves upon a sensitized nervous surface called the retina. By means of refractive agents, forming a part of the eyeball in front of the retina, the light from objects is focused upon it, stimulating in this way an area corresponding in form to the object. The greatest degree of refraction occurs at the cornea, while the crystalline lens serves as the instrument of accommodation. To adapt the eyeballs to their work, they are controlled by muscles; kept constantly moist; and are protected by a variety of agencies.

Review Questions. 1. Under what conditions are light waves reflected, transmitted, and absorbed?

2. What is the origin of the light waves which enable us to see objects?
3. How may the light reflected from an object form an image of that object?
4. What different things must happen in order to see an object?
5. What portions of the eyeball transmit light? What absorb light? What reflect light? What refract light?
6. Show how the iris, the crystalline lens, the retina, the ciliary muscle, and the cornea aid in seeing.
7. Trace a ray of light from a visible object through the different media, to the retina.
8. What change in the shape of the crystalline lens occurs, when we look from a distant to a near object? Why is this change necessary? How is it brought about?
9. Show how the proper lenses remedy short- and long-sightedness.
10. Of what importance are the muscles attached to the outside of the eyeballs?
11. Describe the conjunctiva and give its functions. Why should it be sensitive?

CHAPTER XXI.

THE GENERAL PROBLEM OF KEEPING WELL.

The special hygiene of the different organs of the body having been considered in connection with their study, it still remains to obtain a general view of the problem of keeping well. *Health* may be described as that condition of the body during which each organ does the work devolving upon it and, at the same time, is adjusted in its activity to the other parts of the body. Weakness of any organ which impairs its function or interferes with its adjustment to other parts is known as *disease*. The problem of keeping well consists in part in the detection and removal of the external causes of disease and in part in the building up and strengthening of such organs or parts of the body as may be weak.

Causes of Disease. Disease has its origin in conditions which, by their effect upon the body, weaken one or more of its parts or interfere with its normal method of operation. Some of these conditions are remote and, as those concerned in inherited defects, are beyond the control of the individual. Others are the results of negligence in the observance of well recognized hygienic laws. Others still are of the nature of influences which, like climate, the house in which one lives, or one's method of gaining a livelihood, produce changes in the body, imperceptible at the time, but which, in the long run, profoundly affect the health. And last, but not least, may be mentioned the effect of micro-organisms or germs which are known by the general name of *bacteria*.

Effects of Bacteria. While there are many forms of bacteria that have no ill effect upon the body and others that are thought to aid it in its work, there are many well known varieties which produce effects that are decidedly harmful. They find an entrance into the system through the lungs, the digestive tract, or the skin and, living upon the liquids and tissues, multiply with great rapidity until they permeate the entire body. They not only destroy the protoplasm of

the various tissues, but deposit waste products, called *ptomaines*, which act as poisons. Infectious diseases as measles, smallpox, scarlet fever, tuberculosis, la grippe, and diphtheria are due to specific forms of bacteria which are able to pass from those having the disease to those who are well—a fact which accounts for their contagious nature. Other diseases as typhoid, yellow and malarial fevers, cholera, and blood poisoning are due also to specific forms of bacteria. In addition to these it is quite probable that many forms of bacteria exist whose effects are not so marked, but which interfere with the normal condition of the body.*

Prevention of Bacterial Diseases. In preventing the spread of infectious disease the problem belongs as much to the community as to the individual. In fact the spreading of such diseases as smallpox and yellow fever, can only be checked by the co-operation of the community under the direction of the strong arm of the law. Isolation of individual patients and of infected neighborhoods is absolutely necessary and, while this may inflict hardship on the few, it is the only safeguard for the many. Great care must be exercised that nothing used in connection with the sick shall serve as a retainer or carrier of germs. All clothing, bedding, or furniture should be thoroughly disinfected or burned. All discharges from the body of the sick should be treated with disinfectants and buried deeply at a remote distance from any water supply to the house. Buildings in which the sick have been cared for should be thoroughly disinfected and cleaned before they are again occupied. The walls of the rooms should be repapered or calcimined and the woodwork repainted, while the out buildings should also be disinfected and cleaned—the object being to completely destroy any germs which, if left, might cause a fresh breaking out of the disease.

In combating bacteria of less virulent types, the attention should usually be directed to conditions in the home or immediate neighborhood that are responsible for their development or transportation. Conditions for their development are fully supplied by places containing decaying vegetable or animal products, moisture, and a moderate degree of warmth. Marshes, cesspools, damp cellars, poorly lighted and ventilated rooms, and all places of filth produce bacteria of many

*The arctic explorer Nansen states that during all the time that his party was exposed to the severe chill of the arctic region, no one was attacked by a cold, but on returning to a warmer climate they were subject to colds as usual. The difference he attributes to the absence of bacteria in the severe arctic climate.

kinds in abundance. The water which one uses may, if it contains a small per cent of organic impurities, support such dangerous bacteria as those of typhoid fever. This water becomes especially dangerous when the supply is low and the impurities are concentrated. Fruits and vegetables, because of the localities of their growth or method of storage, may also contain dangerous bacteria. Impure water should be thoroughly boiled and all food suspected of being contaminated, should be thoroughly cooked before using. The common dust everywhere so prevalent during the summer and so abundant indoors in the winter, is an important factor in the spreading of bacteria. Air containing dust should be breathed as little as possible and only through the nostrils. When one is compelled, as in the sweeping of halls or rooms, to breathe dust-laden air for some time, he should inhale through a moistened sponge or cloth secured in front of the nostrils. Domestic pets as well as household pests—rats and mice and various insects—are also responsible for the spreading of certain forms of bacteria.*

Sanitary Condition of the Home. Much of the danger from bacteria may be prevented by instituting and maintaining proper sanitary conditions in and about the home. The home, being the feeding and resting place of the entire family, and the place where every one spends a large part of his time, is the most important factor in one's physical, as well as moral, environment. For this reason there is no place where careful attention to hygienic requirements will yield better results.

One of the first requisites of the home is a suitable location for the house. The house should be built upon ground that is well drained

* It has recently been proven beyond question that the common mosquito is largely responsible for the spreading of the malarial plasmodium. By sucking the blood of those suffering from malaria, and perhaps by other means not understood, he becomes infected with organisms which he injects beneath the skin of his victims who may be well. It is therefore a safe precaution to limit as much as possible the production of mosquitoes in any neighborhood. All small bodies of standing water should be drained or, where this is not possible, covered with a thin layer of kerosene.

The common house-fly is also an important agent in the spreading of bacteria. Feeding as it does on filth of all kinds, it is easy for it to transfer the bacteria that may stick to its body, to the food which is supplied to the table. Screens should be employed for keeping flies out of the house and material in which they develop, such as the refuse from stables, should not be allowed to accumulate.

and, if natural drainage is lacking, artificial drainage should be supplied. No marsh or swamp should be within a quarter of a mile of the house and, if so near, should be in the direction toward which the wind usually blows. A stone foundation should be provided and there should be left at least eighteen inches of ventilated air space between the ground and the floor. Ample provision should be made for pure air and sunlight in all the rooms. The cellar, if one is desired, should be constructed with special care. It should be perfectly dry and provided with windows for both light and ventilation. Adequate means should be provided, by sewage pipes and other means, for the disposal of all waste from the kitchen. Where drainage pipes are provided, care must be taken to prevent the entrance of sewer gas into the house and also the passage of material from these pipes into the water supply. The placing and connecting of sewer pipes should always be under the direction of an expert mechanic.

But it matters not how carefully a house has been constructed from a sanitary standpoint, it requires the constant care of an intelligent housekeeper to keep it a healthful place in which to live. Daily cleaning and airing of all living rooms is necessary while such places as the kitchen, the cellar, and closets need extra thoughtfulness and, at times, hard work. Moreover the problem is not all indoors. The immediate premises must be kept clean and sightly. All decaying animal and vegetable matter should be removed. Rubbish of any kind must not be allowed to accumulate and disinfectants should be used freely. It is thus seen that home sanitation consists not of one, but of many problems, all more or less complex and none of which can be slighted or turned over to the novice. Not the least of such problems is that of providing an adequate and healthful

Water Supply. Water very readily takes up and holds the impurities with which it comes in contact and for this reason should either be exposed as little as possible in the process of collecting or separated from its impurities afterward. Where cistern water is used care must be taken to prevent filth from the roof, waterpipes or soil from getting into the reservoir. Where no means of filtering is provided, water should be collected from the roof only after it has rained long enough for the roof and pipes to have been cleaned, and water should be collected in the winter time rather than in summer. The cistern should have no leaks and the top should be inclosed to prevent the accidental falling of small animals or rubbish into the water.

Shallow wells are to be condemned, as a rule, because of the likelihood of surface drainage and water from springs should, for the same reason, be used with caution. Deep wells, that are kept clean, usually may be relied on to furnish water free from organic impurities, but such water often holds in solution so much of mineral impurities as to render it unfit for drinking purposes.

Relation of Vocation to the Health. With a few exceptions, the pursuit of one's vocation or calling in life does not supply either the quantity or kind of activity that is most in harmony with the plan of the body. Especially is this true of work that requires most of the time to be spent indoors and which exercises but a small portion of the body. The effect of such vocations, if not counteracted, is to weaken certain organs of the body, thereby disturbing the functional equilibrium of its parts—a result that may be brought about either by the overwork of particular organs or through lack of sufficient exercise of others. Herein lies the explanation of the observed fact that people of the same calling in life have similar diseases. If, as too often happens, the vocation is pursued under conditions of strain, or during periods that are too prolonged, exhausting the entire body as well as the organs most directly concerned, the effect is to intensify the tendencies incident to the work and to induce additional forms of weakness. The avoidance of whatever tendencies to disease that may exist in one's calling in life, is necessary both because of their bearing upon one's ability to work and upon the ability of the body to resist attacks of bacteria.

The Remedy lies in two directions—that of spending sufficient time away from one's work to allow the body to regain its normal condition and that of counteracting by special exercise or other means the effect of the work. In most cases the first symptoms of weakness indicate a suitable remedy. Thus exhaustion from overwork suggests rest or recreation. The diverting of too much blood from other parts of the body to the brain suggests some form of exercise or work which will equalize the circulation. If feebleness on the part of the digestive organs is being induced, some natural method of increasing the blood supply to these organs is to be looked for, while effects arising from lack of fresh air and sunlight are counteracted by the spending of more time out of doors.

In the counteraction of tendencies to disease and in the maintenance of the functional equilibrium of the body, no agent has yet been discovered of

greater importance than physical exercise, when applied systematically and persistently. This may consist of exercises which call into activity, with more or less uniformity, all the muscles of the body or that which may be concentrated upon special parts. Where general tonic effects are desired, the exercise should be well distributed, but where counteractive and remedial effects are wanted it must be applied chiefly to the parts that are weak or that have not been called into action by the regular work. Unfortunately health is sometimes confused with physical strength and the exercise directed mainly to the stronger parts of the body with the effect of making them still stronger. Not only is health not to be measured by the pounds one can lift or some gymnastic feat one may be able to perform, but the possession of great muscular power may, if the heart and other organs be not proportionately strong, prove a menace to the health. This being true, one having his health primarily in view will use physical exercise in part, at least, as a means of diverting an increased blood supply to the parts that are weak.

Since the body, like a chain, can be no stronger than its weakest part, this is clearly the logical method of fortifying it against disease.

Value of Work. Since there may exist in the nature of one's vocation certain causes of disease, it must not be inferred that work, in itself, is detrimental to the health. Such an inference would be erroneous and not at all in keeping with the plan of the body. Health demands activity and those forms of activity that provide a systematic outlet for one's surplus energy and compel the formation of regular habits of eating, sleeping, and exercise best serve the purpose. Work furnishes activity of this kind and serves also as a safeguard against the unhealthful and immoral habits contracted so often from idleness. Even physical exercise, which has for its purpose the counteraction of tendencies to disease, may frequently be of the nature of useful work without at all diminishing its desired effects.

The Mental Attitude. While a proper thoughtfulness and care for the body is both desirable and necessary, it is also true that over-anxiety about, or an unnatural attention to, the needs of the body, is objectionable from a hygienic standpoint. Observance of the laws of health, therefore, should be natural and, without special effort, as a matter of habit. The attention should never be turned with anxiety upon any organ or process, but the mental attitude should at all times be that of confidence in the power of the physical organization to do its work without aid or interference. Fear, which is a disturbing and paralyzing factor in the animal economy, must if possible be supplanted by courage and hopefulness.

Nor does living hygienically preclude the idea of strenuous effort. The plan of the body is such as to withstand great strain and hard

usage, if they be not too prolonged, in fact, to meet any and all ordinary demands that may be made upon it. Hygiene means nothing more than the application of the same intelligence and practical common-sense to the care of the body that the skilled mechanic would apply to an efficient but intricate and valuable piece of machinery. And, just as in the case of the machine, care of the body keeps its efficiency at the maximum and lengthens the period that it may be used. This end and aim of hygienic living are best attained by cultivating that attitude of mind toward the body which avoids interference in the vital processes and which permits the natural appetites, sensations, and desires to indicate very largely the needs of the body.

Summary. The solution of the problem of keeping well is, for each individual, the living of that life which is in closest harmony with the plan of the body. Such a life, because of differences in physical organization, as well as differences in environment and occupation, cannot be the same for all persons. All, however, must observe the conditions under which the body may be used without injuring it and the special hygienic laws relative to the care of particular organs. Causes of disease, whether they be found in one's environment, vocation, or method of recreation must be avoided or counteracted.

While the problem is beset with such difficulties as lack of sufficient knowledge, inherited weakness, and time and opportunity for doing what is known to be best for the body, yet study and work that has for its aim the preservation or improvement of the health is always worth while. *Health is its own reward.*

Practical Questions. 1. State the important differences between a condition of health and one of disease?

2. In what general ways may disease originate in the body?

3. What conditions in the life of a student may, if uncounteracted, lead to poor health?

4. In what different ways may one's physical environment affect his health?

5. Describe a model sanitary home.

6. Of what special advantage are the parks and pleasure grounds in a city to the health of its inhabitants?

7. Describe the necessary precautions for preventing the spread of infectious diseases.

8. How are the bad effects of indoor life to be counteracted?

9. Describe the general methods of preventing the entrance of bacteria into the body.

10. Discuss the hygienic value of work.

SUMMARY OF PART II.

The body or cell group must have its parts controlled and co-ordinated. It must be moved from place to place. It must be constantly adjusted in its various activities to the physical conditions surrounding it. To accomplish these purposes there is employed:

1. The skeleton which supplies a framework, the parts of which are movable upon each other, making of the body a machine capable of motion.

2. The muscular system which supplies the necessary force for moving the machine.

3. The nervous system which (a) controls and co-ordinates the various activities and (b) provides for the *intelligent* management of the body.

(Review plan of the body, page 5, and general summary, page 92, and consult figure 1.)

APPENDIX.

To Prepare Oxygen. Mix thoroughly a heaping teaspoonful of potassium chlorate with half as much manganese dioxide and place in a test tube six inches long. The top of the tube should be tightly closed with a cork, through which passes the end of a small glass tube 15 inches in length. To secure the proper shape for passing the gas into receivers, this tube should be bent nearly at right angles about an inch above the cork and again slightly, about one-half an inch from the other end.

For collecting the gas a wash basin and several large-mouthed bottles are required. Fill each bottle even full of water, place a stiff piece of paper over the mouth, and invert, without spilling, in the pan, which should contain water to the depth of three-fourths of an inch.

When everything is ready heat the test tube over the flame of an alcohol lamp, bringing it near enough for the flame to spread over the end of the tube. When the gas begins to pass off insert the end of the tube under one of the bottles. Leave the bottles of gas inverted in the pan until ready to use the gas. On removing keep the bottles tightly covered.

To Destroy the Brain of a Frog. For certain experiments in which live frogs are used the most successful as well as the most humane way of managing them is to destroy the brain. This puts the frog under the complete control of the operator and at the same time destroys all sensation.

Make an incision with a sharp knife, over the spinal cord where the head joins the body. Insert the blunted end of a wire, or a large knitting needle, and push it into the cavity occupied by the brain. Probe with the wire in different directions until sure that the different ganglia have been disorganized. When the frog drops into a relaxed and lifeless condition the operation is complete.

To Collect Blood. If only a drop or two is needed it can easily be obtained from the finger. Wrap one of the fingers of the left hand with a handkerchief, from the hand down to the last joint. Bend this joint, give it a sharp, quick blow with the point of a clean pin or needle above the root of the nail. Pressure applied to the under side of the finger will force plenty of blood out through a very small opening. (To prevent any possibility of blood poisoning, the pin and finger may be washed with alcohol before making the incision.)

If blood is needed in large quantities it must be obtained from the slaughter house. To be sure of securing the specimens of blood needed for the experiments

in Chapter II, take to the butcher three suitable vessels, upon which are pasted labels like the following:

1.	2	3
Fill $\frac{2}{3}$ full. While the blood is cooling, stir rapidly with the hand or a bunch of switches to remove clot.	Fill $\frac{2}{3}$ full and set aside without shaking or stirring.	Fill $\frac{2}{3}$ full and thoroughly mix with the liquid in the bottle.

Label No. 3 must be pasted on a bottle, having a tight fitting cork, which is filled one-fifth full of a saturated solution of Epsom salts.

Lime-Water is prepared by dissolving lime in water. Fill a quart jar nearly full of water and add a few small lumps of *fresh* lime. Mix the two and let stand till all the undissolved lime settles to the bottom. This will require a day or more. Pour off and use the clear liquid above the lime. For additional supplies, refill the bottle with water. (Only fresh lime can be used in the preparation of lime-water.)

Dissections are occasionally necessary in the study of physiology in order to obtain definite ideas of the structure and form of organs and tissues. In conducting a dissection care must be taken not to offend the sensibilities of pupils and not to cultivate a disregard for the lives of the lower animals. The skill of the operator and spirit in which the dissection is made have everything to do with the mental attitude of the pupils. A difficult dissection like that of the abdomen should not be undertaken before a class without previous experience on the part of the teacher. Care must always be exercised in the matter of cleanliness and the escape of blood should be prevented as far as possible. The necessity for gaining accurate information at first hand, which is the excuse for the dissection, must be kept prominently in mind.

Equipment. Nearly all of the apparatus and materials called for in this book may be found in the physical, chemical, and biological laboratories of the average high school. There should be ready, however, for frequent and convenient use, the following: One or more compound microscopes with two-thirds and one-fifth inch objectives; a set of prepared and mounted slides of the various tissues of the body; a set of dissecting instruments, including bone forceps; a mounted human skeleton and a manikin or a set of physiological charts; a set of simple chemical apparatus including bottles, flasks, test tubes, and evaporating dishes; and a Bunsen burner or some other means of supplying heat.

The few chemicals required may be obtained from a drug store or from the chemical laboratory. Access to a work bench having a set of carpenter's tools will enable one to prepare many simple pieces of apparatus as they are needed.

Physiological Charts are easily prepared by teachers or pupils by carefully enlarging the more important illustrations found in text-books or by work-

ing out original sketches and diagrams. These, if drawn on heavy Manilla paper, may be hung on the wall as needed and preserved indefinitely. By the use of colors, necessary contrasts are drawn and emphasis placed on parts as desired. The author has for a number of years used such home-made charts in his teaching and has found them quite satisfactory. His plan has been to first draw on heavy Manilla paper, cut in sizes of two by three feet, the general outline in pencil and then to mark over this with the desired colors. There is of course an opportunity for producing results that are artistic as well as practical and if one has time and artistic skill, better results can be obtained. Most of the cuts of this book are excellently suited to enlargement and, if properly executed, will provide a good set for general class purposes.

A more expensive, but better method in the end, is that of making the drawings upon white window shades with water proof ink or with colored crayons. The rollers, if left attached, may be secured permanently to the wall and the drawings pulled down as they are needed.

If the crayon colors show a tendency to rub off they may be "fixed" by spraying the drawing with a solution of shellac in alcohol. Artist's crayons, however, may be obtained that adhere to the paper or cloth.

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